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An Inventory of Used and By-Product Hydrocarbon Streams

ETA Engineering, Inc.
Westmont, IL

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AN INVENTORY OF USED AND BY-PRODUCT HYDROCARBON STREAMS

by

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This study identifies and characterizes major used and by-product gaseous and liquid hydrocarbon streams and estimates their recovery potential. The magnitude of these streams is established by applying emission factors to a relevant base variable, such as the quantity of new material used or produced. The recovery potential is examined by proposing the application of reasonably available control and recycling technology to each source category. In addition to reviewing reclamation techniques for used hydrocarbon streams, present disposal methods are reviewed. Some energy and economic implications of alternative recycling and disposal methods are discussed. The study concludes by recommending areas for further research, areas where there appears to be significant potential for recovery from used hydrocarbon streams.

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

Industry generates large quantities of used and by-product gaseous and liquid hydrocarbon streams, which are too often wasted or improperly disposed of. This report identifies the major sources of such hydrocarbon streams and estimates their recovery potential. Further, this report briefly discusses the applicable control and reclamation techniques for source categories with significant recovery potential. The findings and recommendations of this study will be used by the Office of Research and Development of the U.S. Environmental Protection Agency to initiate programs to reduce the quantities of used hydrocarbon streams and/or to reuse them in an environmentally safe manner. The Alternate Energy Sources Branch of the Energy Pollution Control Division should be contacted for additional information.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

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ABSTRACT

This study identifies and characterizes major used and by-product gaseous and liquid hydrocarbon streams and estimates their recovery potential. The magnitude of these streams is established by applying emission factors to a relevant base variable, such as the quantity of new material sold to industry. The recovery potential is examined by proposing the application of reasonably available control and recycling technology to each source category.

In addition to reviewing reclamation techniques for used liquid hydrocarbon streams, some of the present disposal methods are reviewed. Also some of the energy and economic implications of several alternative methods of recycling and disposal are briefly discussed. The study concludes by making several recommendations for further research in those areas where there appears to be significant potential for used hydrocarbon recovery.

This report was submitted in fulfillment of Contract 68-03-2728 by ETA Engineering, Inc., under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from September 12, 1978, to September 12, 1979. The work was completed as of November 1979.

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SECTION 1

INTRODUCTION

Large quantities of used and by-product hydrocarbon streams are generated by industry each year. Although some efforts have been made to recover and reuse these hydrocarbon streams, large quantities of these are still being wasted or disposed of in an improper manner. Besides the energy loss, there are often hazardous environmental consequences resulting from improper disposal or reuse.

This study was sponsored by the Industrial Environmental Research Laboratory of the U.S. Environmental Protection Agency to identify and characterize major used and by-product hydrocarbon streams including gases and liquids. The study had the following major objectives:

a) Identify major sources of used and by-product liquid and gaseous hydrocarbon streams

b) Develop an inventory of these hydrocarbon streams

c) Review the recovery potential based on a preliminary review of applicable control and reclamation techniques that would reduce the quantities of waste hydrocarbon streams or make them suitable for reuse in an environmentally safe manner

d) Identify and recommend areas of further research and analysis, the results of which would direct improvements in hydrocarbon recovery

The study is organized into four major parts. The bulk of the work is included in Sections 5 and 6, which discuss and characterize major gaseous and liquid hydrocarbon streams. Section 7 reviews the major regulations and programs related to the recovery and control of hydrocarbon streams. The results and conclusions of the study are summarized in Sections 2 and 3, respectively. Section 4 identifies and discusses in detail the recommendations for undertaking further research programs to improve hydrocarbon recovery.

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SECTION 2

SUMMARY AND DISCUSSION OF RESULTS

This summary presents the results of a study conducted to identify and characterize major used and by-product gaseous and liquid hydrocarbon streams. The gaseous used hydrocarbon streams include a variety of source categories, but the emphasis of the study was primarily on source categories with significant recovery potential. Among the used liquid hydrocarbon streams, used oils and used solvents are the major energy-bearing streams that have been emphasized in this study. Other streams provide relatively less potential for resource recovery.

GASEOUS HYDROCARBON STREAMS

The VOC recovery potential estimated in this study was based mainly on the review of Reasonably Available Control Technology (RACT) for major source categories, as discussed in the Control Technique Guideline (CTG) documents. These documents were developed by the U.S. EPA to help various states in revising their State Implementation Plans (SIP) under the requirements of the Clean Air Act, as amended. These SIP revisions include proposed regulations to control Volatile Organic Compound (VOC) emissions from most major VOC sources. Although the state regulations have been proposed simply to reduce the VOC emissions going into the atmosphere, these will also result in significant recovery of VOC's. Much of the recovery potential for gaseous hydrocarbons estimated in this study will probably be achieved in the next few years when the proposed state regulations are finalized and implemented. However, these regulations will not be applicable to small sources and to sources located in rural areas because of economic and air quality considerations. Therefore, the recovery achieved through the SIP revisions will be less than the figures estimated in this study, and additional recovery through a broader application of RACT is possible. The extent of additional emission reductions cannot be determined until an analysis of revised state regulations can be completed. Some of the state regulations requiring RACT for the first fifteen source categories are now in effect, with many states now writing regulations incorporating the more recently available RACT guidelines for other point sources of VOC emissions.

Discussion of Results by Source Category

For the purposes of this study, gaseous hydrocarbons were referred to as VOC to include some organics that are not hydrocarbons according to the strictest definition. However, the effects of these organics on the environment and their recovery potential are as significant as the effects and recovery potential of pure hydrocarbons. Table 1 presents a summary of the VOC emissions from major source categories with significant recovery potential and a preliminary estimate of the possible savings. The reduction potential included in Table 1 represents the possible reduction in VOC emissions achieved through the application of control technology. This technology can be add-on control equipment (incinerators, carbon adsorbers, etc.) or process changes. Recovery

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TABLE 1. SUMMARY OF VOC EMISSIONS AND THEIR REDUCTION AND RECOVERY POTENTIAL[a]

Source Category	Estimated VOC Emissions (10^3 Metric Tons/yr)	Estimated Reduction Potential (10^3 Metric Tons/yr)	Estimated Recovery Potential[b] (10^3 Metric Tons/yr)
Petroleum Refineries[c]	1,202	987	892
Gasoline Marketing	1,451	1,113	1,113
Solvent Evaporation	7,007	1,741-1,831[d]	707-797[d]
Industrial Manufacturing[e]	672	71[d]	NA[f]
Solid Waste Disposal	1,156	1,040	1,040
Stationary Fuel Combustion	694	NA[f]	NA[f]
Crude Oil Production	325	NA[f]	NA[f]
TOTAL	12,507	4,952-5,042[d]	3,752-3,842

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[a] The table includes only those source categories which were considered in this study.

[b] Estimated recovery potential is sometimes less than the reduction potential because of the manner in which reduction is achieved. For example, reduction through incineration will not result in recovery, since the emissions are being destroyed, not recovered.

[c] Includes emissions from refinery operations, crude oil transportation and storage at refineries.

[d] Figures do not represent national totals. The savings could not be develope for all source categories because of insufficient data.

[e] Includes only the major manufacturing processes.

[f] NA -- Not Available. These values could not be developed because of insufficient data.

potential represents the quantities that can be recovered as a product suitable for reuse as a fuel or as an industrial product. The following major industrial categories were included in this study:

Petroleum Refineries
Gasoline Marketing Facilities
Solvent Evaporation
Industrial Manufacturing
Solid Waste Disposal
Stationary Fuel Combustion

Petroleum refineries emit approximately 1,202,000 metric tons/yr of VOC. This estimate is for uncontrolled emissions and includes emissions from the storage of petroleum liquids at refineries, the transportation of crude oil to refineries, and refinery process operations. Most of the petroleum liquid storage emissions at refineries are due to storage in fixed roof tanks. The RACT for this source category is to retrofit fixed roof storage tanks with internal floating roofs or with a vapor recovery unit, internal floating roofs being more common for reasons of economy. Most of the states have proposed regulations in their SIP revisions to control these emissions by the application of RACT. However, these regulations are expected to cover only large storage tanks (over 400,000 gallons for crude oil storage and 40,000 gallons for other volatile petroleum liquids) because these are the most cost-effective to control. Therefore, the VOC reduction due to the implementation of proposed state regulations will be less than the total achievable reduction. Most of the VOC emissions due to the transportation of crude oil occur during unloading operations. These emissions can be adequately controlled through the use of vapor recovery equipment.

The refinery process sources contribute approximately 58 percent of the total uncontrolled refinery emissions. Most of these emissions are either flared or used as fuel. They are not recovered because of their low concentrations, the high volumes of exhaust gases to be handled, the minimal reuse potential, and other technical considerations. A significant part of refinery emissions is due to leaks from refinery equipment. These emissions can be reduced (and recovered) by instituting a monitoring and maintenance program to locate and repair the leaks. Presently, there are no quantitative data available on the VOC reduction capabilities of such programs. The estimated emissions from the storage of petroleum liquids at refineries are 448,000 metric tons/year; from the transportation of crude oil to refineries, 58,000 metric tons/year; and from refinery process sources, 696,000 metric tons/year. From the total of 1,202,000 metric tons/year of VOC emissions at petroleum refineries, a reduction of 987,000 metric tons/year can be achieved through the application of control technologies. The estimated recovery potential is 892,000 metric tons/year. The estimated recovery potential is less than the estimated reduction potential because VOC emissions from the catalytic cracking units is achieved through incineration, which does result in any recovery of these emissions.

Gasoline marketing facilities include bulk terminals, bulk plants, and gasoline dispensing facilities. The RACT for loading/unloading operations at these facilities includes (1) vapor balance systems at bulk plants and at dispensing facilities to collect the vapor and (2) a vapor recovery unit at the bulk terminal. The vapor collected at bulk plants and at dispensing facilities is transported to bulk terminals for recovery. The storage tank losses are controlled by retrofitting internal floating roofs on fixed roof tanks. The total VOC emissions from gasoline marketing facilities are estimated to be approximately 1,451,000 metric tons/year.

The application of RACT to these facilities will recover 1,113,000 metric tons/year. Presently, the only VOC emission control being employed at gasoline marketing facilities is for large capacity petroleum liquid storage tanks. Regulations have been proposed by various states in their SIP revisions to control VOC emissions from these facilities. For economic reasons, however, these regulations will be applicable mostly to high throughput facilities. Also, some facilities located in rural areas will probably be exempted from the regulations because of lower ozone levels. Therefore, the actual recovery attainable through the implementation of the proposed rules in various states will probably be less than the recovery achievable through a uniform application of RACT to all sources.

VOC emissions due to solvent evaporation are the largest contributors to the total VOC emissions from stationary sources. Major source categories under this classification include surface coating applications, degreasing, dry cleaning, use of cutback asphalt, and graphic arts. (Individual emission totals from these source categories are given in Table 29, Section 5.) Surface coating applications account for approximately 1,753,000 metric tons/year of VOC emissions. Out of these, 778,000 tons are due to the use of trade paints and, therefore, cannot be controlled or recovered. (Trade paints are shelf products sold through retail stores to the general public, to professional painters, and to builders).

VOC emissions from industrial surface coating applications (975,000 metric tons/year) can be controlled by various control techniques which have been judged as RACT for these applications. The extent of recovery will depend greatly on the emission control method used by the industry. Major control methods available to the industry include the use of low solvent coatings or add-on control devices (incineration, carbon adsorber, etc.). Most of the low solvent coatings are presently in the developmental stage and may not be available for commercial applications in the near future. Among the add-on control devices, incineration is often the preferred technique because of its applicability to a wide range of process characteristics and its often lower costs.

The application of RACT to the industrial surface coating applications can reduce the VOC emissions by 878,000 metric tons/year. The recovery potential will depend on the extent of use of various control technologies which, in turn, depends on the application, the concentration of organics in the exhaust gases, the reuse potential of recovered materials, and other technical and economic factors. Since the various state regulations on surface coating applications require RACT to be applied by 1982, low solvent coating alternatives will probably not be available to the industries as a control method because additional developmental work is required for commercial use. The choice between a carbon adsorber and an incinerator will depend on many factors as stated above. For these reasons, it was not possible to estimate the VOC recovery potential from surface coating applications.

Dry cleaning applications contribute approximately 227,000 metric tons/year to the atmosphere. RACT for perchloroethylene (perc) dry cleaning includes the use of condensers or carbon adsorbers to recover VOC emissions. Two other groups of solvents used by dry cleaners are petroleum solvents and fluorocarbon solvents. Although fluorocarbons are practically inert, petroleum solvents are highly combustible, and the use of emission reduction equipment in controlling petroleum solvents has not been demonstrated in the United States on an operating scale. The potential VOC recovery from perc dry cleaning operations is expected to be approximately 92,000 metric tons/year. Presently, about 35 percent of the commercial units and 50 percent of the industrial perc dry cleaning units are controlled. Most of the remaining large uncontrolled perc dry cleaning plants are expected to be controlled when RACT is required in some states. However, depending on economic and air quality considerations, these regulations may not require RACT on a uniform basis for all sources, and therefore, the VOC recovery attainable through the regulatory process may be less than that estimated in this study.

The degreasing applications emit approximately 836,000 metric tons/year of VOCs. RACT for this source category has been defined as a control system (instead of a single control) based on the use of add-on control devices and improved operational practices. Two basic control systems have been recommended in the EPA Control Technique Guideline (CTG) document for this source category. For degreasing operations, the reduction potential is also the recovery potential. A uniform application of these systems on all the degreasers can reduce VOC emissions by 300,000-470,000 metric tons/year, depending upon the control system used. The overall control efficiency is relatively low because the suggested control system mainly reduces the bath evaporation and solvent carry-out emissions. Further recovery beyond the application of RACT is possible through proper handling and reclamation of waste solvents. This is discussed in detail under "Other Used Liquid Solvent Streams" in Section 6.

Control technology for the reduction of VOC emissions from the use of cutback asphalt is based on the elimination of emissions through the substitution of cutback asphalt with emulsified asphalt. The total VOC emissions from this source category are 470,000 metric tons/year; approximately 235,000 metric tons/year of these emissions can be reduced through the application of the above technology.

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Graphic art (printing and publishing) applications account for approximately 240,000 metric tons of VOC emissions per year. The application of RACT to these applications can reduce the VOC emissions by approximately 156,000 metric tons/year. The extent of possible recovery depends on the control technology used (incineration, carbon adsorption, or low solvent coating).

Besides the major solvent using applications previously mentioned, several other miscellaneous applications emit significant quantities of VOC when taken together. These include the manufacture of adhesives, aerosal applications, and architectural surface coating. Based on a total solvent consumption of approximately 7 million metric tons/year, these miscellaneous applications account for approximately 3.5 million metric tons of VOC emissions (assuming that VOC emissions equal the quantity of solvent consumed). Limited data precluded any analysis of VOC recovery potential from these other source categories.

Industrial manufacturing operations include a variety of organic manufacturing industries that emit VOC. Emissions from the major organic manufacturing operations are estimated to be approximately 700,000 metric tons/year. No RACT guideline has been developed for this source category. Most of the existing technical studies have emphasized incineration with heat recovery as the major control technique for process VOC emissions from organic manufacturing industries. However, these studies were mostly directed at controlling VOC emissions and not necessarily recovering these emissions. It is possible that some of the organics could be recovered through refrigerated scrubbing; some other organic compounds, like benzene and toluene, could be recovered through the carbon adsorption process.

The disposal of solid wastes in landfills generates significant quantities of waste gases which include approximately 52 percent hydrocarbons. The major recoverable constituent is methane which, when recovered, can be used as a fuel source. The VOC emissions from solid waste disposal have been estimated to be approximately 1,156,000 metric tons/year. Potentially, 90 percent of these emissions can be recovered. However, there are some technical and economic barriers to realizing this energy savings.

LIQUID HYDROCARBON STREAMS

Used oils and used solvents are the major used liquid hydrocarbon streams with significant recovery potential. In addition to these, other major but less significant streams of used liquid hydrocarbons are generated from the basic organic manufacturing industries.

Used Industrial and Automotive Oils

Used oils are generated chiefly in the primary metal and metalworking industries and in the transportation sector. Industrial lube oils include water soluble cutting oils, straight cutting oils, hydraulic oils, and gear and transmission oils. Non-lube industrial oils include heat treating oils, transformer oils, refrigeration oils and process oils. Railroad engine oils are also grouped into the industrial category by the Bureau of Census. Oils found in the transportation sector include oils from automotive, truck, and aviation sources. These oils are mainly engine oils, hydraulic fluids, and other miscellaneous lube oils.

The total oil usage for the year 1977 has been estimated to be approximately 11.0 billion liters. Out of this, industrial oils account for approximately 6.1 billion liters and automotive oils account for approximately 4.9 billion liters. The consumption of aviation oils is 0.08 billion liters. The quantity of used oil generated depends on the usage category (industrial, automotive) and the major application in each category. The total quantity of used oil generated has been estimated to be approximately 5.4 billion liters, of which 2.7 billion liters are from the industrial sector. The balance of 2.7 billion liters is from the transportation sector.

Theoretically, almost all of the used oil generated should be recoverable. However, the percentage that is actually, technically and economically, feasible to recover depends on many variables including the oil type, level of contamination, storage facility and location. Approximately 50 percent of all engine oil is sold to "do-it-yourselfers" (DIYs), who change their own motor oil or add oil to make up for the volume lost in the engine. Most of these DIYs use environmentally unsatisfactory methods of disposal which presently provide little chance for collection and reuse. The collection of this oil presently poses the major challenge in improving the recoverability of used automotive oils.

In the case of used industrial oils, the present recovery is almost insignificant as compared to the total used oils generated. Some of the reasons for this are poor handling and maintenance procedures, poor oil use and disposal accounting, inadequate used oil storage and stream segregation, and insufficient knowledge of techniques for extending oil life and recycling used oils. Another important reason is that industry is not fully aware of the recovery or reuse potential of the used oils if they are properly segregated, stored, and treated. Development of an oil conservation program covering the extensive audit of the oil usage and disposal practices, economic analyses of various reuse options, improvements in the present operation and maintenance practices, and the energy implications of the various reuse/disposal methods can all significantly improve the collection and recovery of used industrial oils.

Used Solvents

Used solvent streams are generated from those applications where they retain their basic chemical identities after use. The recovery potential depends on many factors, including the level of contamination, the application, the type of solvent, and the reuse potential.

The consumption of some selected virgin solvents in major categories of commercial application is estimated to be approximately 4.7 million metric tons/year. This estimate was derived by considering halogenated hydrocarbons, ketones, and alcohol-based solvents, which are not used exclusively as "chemical building blocks" but are also employed in applications in which they retain their basic chemical identities after use. It is difficult to estimate the quantities of used solvents generated, the wide variety of industrial applications, losses into the atmosphere during use (because of their high volatility), a dependence on operational procedures (which vary widely from application to application), and poor accounting procedures in the plants all adding to this difficulty. Another complicating factor is the rapid evaporation rate of used solvents when stored in the open. It is expected that used liquid solvent recovery potential is very significant.

At present, only a small percentage of the used solvent quantities are being sent for reclamation; the balance is landfilled, incinerated, evaporated into the atmosphere during storage in open containers, dumped, or disposed by other means. About 45 percent of the solvents used in the degreasing industry are recovered. For other industry groups the percentage of used solvents being reclaimed is expected to be considerably smaller than 45 percent. The amount of used solvents reclaimed could be greatly increased through modifications in operating and maintenance practices, and following better collection procedures.

Other Liquid Hydrocarbon Streams

In addition to used oils and used solvent streams, other used liquid hydrocarbon streams are produced in the manufacture of basic organic chemicals, organic intermediates, plasticizers, and electrochemical resins. Although on a national basis no quantitative data can be easily developed for these streams, they are expected to be significant. These used hydrocarbon streams are normally not suitable for recovery as a product because of high levels of contamination, difficulty of separation, and other technical considerations. However, they can offer a good potential for energy recovery through their use as a fuel. Major factors to be considered in this regard are the composition and heat content of these streams, their quality, the treatment required to make them suitable for use as fuel, and the air pollution aspects of this treatment and usage.

REGULATIONS CONTROLLING USED HYDROCARBON STREAMS

Gaseous hydrocarbon streams are regulated, mainly by the provisions of the Clean Air Act. The original Act and the subsequent amendments in the years 1970 and 1977, have required that the U.S. EPA promulgate National Ambient Air Quality Standards (NAAQS) and that each state adopt an implementation plan to control emissions to attain the NAAQS and to maintain them after attainment. Under the SIP revisions, all the states are presently in the process of proposing regulations to control hydrocarbon emissions based on RACT for all the major source categories.

The major federal regulations governing the conservation and disposal of used liquid hydrocarbon streams are the Resource Conservation

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and Recovery Act (RCRA), Energy Policy and Conservation Act (EPCA), and the Federal Water Pollution Control Act. RCRA, an amendment to the Solid Waste Disposal Act, covers both hazardous and non-hazardous wastes. The Federal Register of December 18, 1978, proposed that the used oil be declared a hazardous material. Therefore, used oils will probably have to meet all the provisions of the section on hazardous wastes. RCRA mainly seeks to strengthen controls over waste disposal practices and to encourage increased recovery and reuse of waste products.

Section 383 of EPCA requires that the Federal Trade Commission (FTC) prescribe a labeling standard for containers of recycled oil, indicating any particular end use for which a determination of the substantial equivalency between the used oil and virgin oil has been made. The purpose of this labeling requirement is to minimize the environmental hazards and wasteful practices associated with the disposal of used oils. The Federal Water Pollution Control Act, as amended by the Clean Water Act, gives the authority to state and local governments to establish waste water pretreatment and discharge standards limiting oil content. Besides the federal regulations on used oil recycling and conservation, several states have also passed some type of legislation related to used oil disposal. These laws support recycling programs and, in some cases, require a manifest system to control disposal practices.

RECOMMENDATIONS FOR FURTHER RESEARCH

Several recommendations have been made based on the conclusions and findings of this study. These recommendations are directed at further investigating and improving the recovery potential of used liquid and gaseous hydrocarbon streams. These recommendations are presented in detail in Section 4.

SECTION 3

CONCLUSIONS

The study on the identification and characterization of used gaseous and liquid hydrocarbon streams and their recovery potential leads to the following conclusions.

Gaseous Hydrocarbon Streams

- The application of RACT (Reasonably Available Control Technology), as discussed in the U.S. EPA Control Technique Guideline (CTG) documents for major source categories, will attain most of the recovery potential estimated in this study. Various states are proposing regulations, under the requirements of the Clean Air Act, to Control Volatile Organic Compounds (VOC) emissions through the application of RACT. However, these regulations generally will not be applicable to small sources or to sources located in rural areas, primarily because of differences in economics and air quality impacts. Therefore, the recovery achieved through regulatory efforts will be less than the quantities that can be recovered by a uniform application of RACT to all VOC sources.

- There are some source categories for which no RACT has yet been developed. These include some solvent-using applications and industrial manufacturing operations. At present, there are few data available on the solvent use patterns and VOC emissions from these applications. These sources, when taken together, emit significant quantities of VOCs. Therefore, identifying these source categories, their solvent consumption patterns (for solvent-using applications), and the possibility of VOC recovery is of value. For industrial process emissions, most of the existing technical studies have emphasized incineration with heat recovery as the major control technique. However, these studies were mainly directed at controlling the VOC emissions, not recovering them. A review of other control techniques and their application to industrial manufacturing processes shows that in many cases additional VOC recovery is possible.

- In the case of surface coating applications, the use of low solvent coatings is the best method of control from an energy recovery standpoint. However, most of the low solvent surface coatings are still in the developmental stage and probably will not be available as a viable control option to meet the air pollution regulations in the stipulated time period.

- Large quantities of methane gas are generated at solid waste landfills. At present, only a small fraction of methane is being recovered for use as fuel. Some technical and economic barriers still stand in the way of tapping this resource.

Further development in this area might result in a significant energy saving.

Liquid Hydrocarbon Streams

- Used oils and used solvents are the two major used liquid hydrocarbon streams with significant recovery potential. Other major but less significant used liquid hydrocarbon streams are generated in basic organic manufacturing industries.

- The quantities of used industrial and automotive oils generated every year are 5.4 billion liters, of which only an insignificant part is presently being recovered and reused. Major reasons for this low recovery are (1) poor handling and maintenance procedures, (2) poor oil use and disposal accounting, (3) inadequate used oil storage and stream segregation, and (4) insufficient knowledge of techniques for extending oil life and for recycling used oils.

- Large quantities of used solvents are also generated every year. However, these quantities cannot be precisely estimated because of the wide variety of industrial applications and because of atmospheric losses during storage in open containers, a result of high solvent volatility. In addition, the quantities of used liquid solvent produced depend upon operational procedures that vary from application to application. At present, only a small percentage of used solvents is being sent for reclamation; the balance is landfilled, incinerated, lost through evaporation, dumped, or disposed of by other means.

- Used liquid hydrocarbon streams other than used oils and used solvents often provide little potential for recovery as a product because of the high levels of contamination, the difficulty of separation, and other technical considerations. However, they can offer good energy recovery potential through their use as a fuel.

SECTION 4

RECOMMENDATIONS FOR FURTHER RESEARCH

Current awareness of energy shortages and dwindling supplies of non-renewable resources has resulted in the initiation of various state and federal programs to identify methods to conserve and recover these resources whenever possible. The present study develops an inventory of the major used hydrocarbon streams and makes a preliminary review of their recovery potential. Based on the review of hydrocarbon sources, their emissions, control technologies, and recovery potential, the following additional programs are recommended to improve the recovery potential of used hydrocarbon streams and to review the energy implications of some control/recovery processes.

CONTROL AND RECLAMATION OF USED INDUSTRIAL OIL

It is estimated that approximately 70 percent of all used industrial oils cannot be readily accounted for in the industrial plant. The fraction of total annual industrial oil demand represented by re-refined and reused lubricants is about 10 percent. The quantity of used oil generated that can be reused in some manner with pretreatment is estimated at about 50 percent of the new oils used. Considering that the annual industrial oil usage in the United States in 1977 was approximately 6.1 billion liters, there is a significant energy potential associated with better recovery and greater reclamation of used industrial oils.

At present there are both energy-saving and economic reasons for recycling used oil in the industrial plant, but even greater incentives to recover oils will exist as a result of RCRA (Resource Conservation and Recovery Act). The December 18, 1978, Federal Register proposes that used oil be declared a hazardous material. If this definition holds, the final regulation will require the industrial plant to keep track of its disposed oils. Although this requirement may make recycling used oils a better alternative than direct disposal, i.e., landfilling or incinerating, most plants will probably remain unaware of the benefits of proper stream segregation and recovery techniques.

Until now, very little work has been done to study the lubricating oil use patterns in industrial plants and to develop programs to improve their reuse potential. The State of Illinois funded a preliminary study in 1977-78 to prepare an "Oil Audit and Reuse Manual for the Industrial Plant." This study was conducted by ETA Engineering, Inc., and the resulting manual was published in November 1978 by the Illinois Institute of Natural Resources, Chicago (Document No. 78/35). This manual describes measures to locate and control the amount of recoverable oil in the industrial plant, and it also analyzes in-plant reclamation techniques. Other control measures described are improved maintenance and operational practices, analysis of reclamation problems, and in-plant analysis of oil. The manual also covers in-plant reclamation equipment and presents an outline for performing an economic evaluation of reclamation programs. This manual is intended to be a general document in this area and provides only preliminary evaluations and generalized conclusions concerning oil conservation and the reclamation of used industrial oils.

Additional work should be undertaken in this area to perform a detailed industry-specific study auditing industrial oil use, evaluating used oil disposal practices, recommending better operational and maintenance practices to improve the quality and life of oil, and analyzing the economics of alternative uses and disposal methods for used oil. The work should be performed in close contact with the industries including primary data collection at the plant among the following major tasks:

a. Examine the existing operational and maintenance practices in selected industrial plants. An oil conservation and improved maintenance program throughout a manufacturing plant can result in increased production, a reduction in oil loss, and reduced waste disposal costs. Recommendations may be made regarding improvements in operation to increase oil life and improve the reclamation potential for used oil. An example of the latter would be used oil stream segregation.

b. Recommend control measures for proper accounting of new and used oils. Industrial plants are often unaware of this potential source of energy waste through indiscriminate disposal of used oils. An oil accounting procedure will identify the various incoming and outgoing streams of oil, used oil disposal practices, and the avenues of oil loss. A sample flow chart for performing a plant oil audit is presented in Figure 1.

c. Review and analyze in-plant reclamation techniques with regard to their suitability and economics. Used industrial oils are generally deemed unsuitable for their original application(s) because of physical contamination from water, dust, and metal fines. Depending upon the extent of contamination, these contaminants can sometimes be easily removed in the plant itself through the use of physical reclamation equipment (centrifuges, filters, settling tanks, etc.). The oil so reclaimed can be as good in quality as the virgin oil. If oil/water emulsions are present in used oil, the demulsifying chemicals can be used to coagulate these; then, further reclamation can be carried out to achieve the desired purity. The development and study of the various in-plant reclamation systems with regard to their effectiveness, economics, and performance is therefore recommended. The main purpose of the study will be to suggest the most effective in-plant reclamation system(s) for industrial plants based on the following considerations: operational feasibility, the amount of used oil generated, the type and extent of contamination, and economics.

The proposed study would result in a practical in-plant guide to inventorying oils and selecting reclamation techniques, emphasizing the favorable economics of oil recycling where possible.

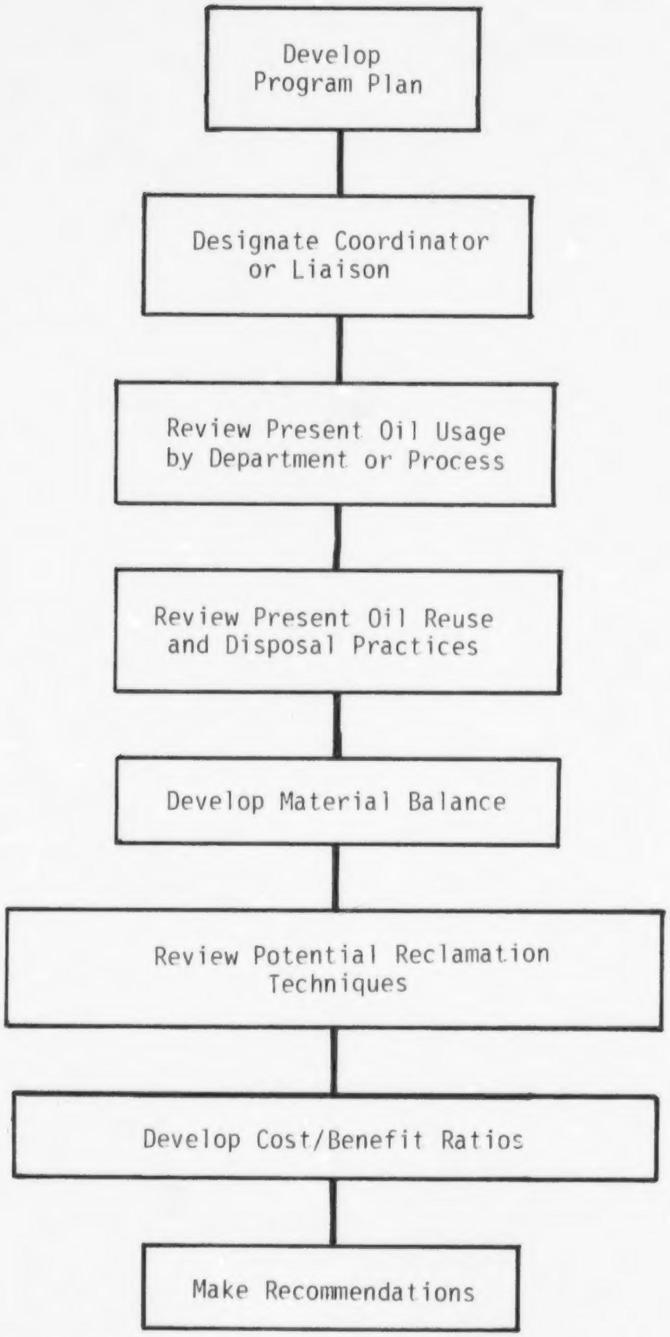
Develop Program Plan
Designate Coordinator or Liaison
Review Present Oil Usage by Department or Process
Review Present Oil Reuse and Disposal Practices
Develop Material Balance
Review Potential Reclamation Techniques
Develop Cost/Benefit Ratios
Make Recommendations

Figure 1. Sample flow chart for plant oil audit.

RECOVERY AND REUSE OF USED SOLVENTS

Organic solvents, like used oils, can be reclaimed by processes like distillation to make them suitable for reuse. Because of their high volatility, most solvent losses are through evaporation. However, a significant fraction of this evaporation loss can be avoided if the used solvent streams are properly handled. And if they are sent for reclamation rather than being dumped or allowed to evaporate in open storage tanks.

The total consumption of solvents in the U.S. is quite large. For example, solvent consumption in degreasing applications is approximately 830,000 metric tons/year. A recent study presented the following distribution for the disposal of used solvent streams (generated from degreasing operations) by the method of disposal.

	Used Solvent Destination	Percent of Used Solvent Handled
1.	Dumping, open storage containers, municipal or chemical landfills, and deep well injection	35
2.	Mixed with waste crankcase oil by waste collector	15
3.	Properly controlled incineration	5
4.	Reclamation	45

The quantities of used solvents being reclaimed are expected to be considerably smaller than 45% for applications other than degreasing. The paint, surface coating, ink, graphic art, and pharmaceutical industries are some of the other applications that produce significant quantities of used solvents. The used solvent streams from these applications can be recycled and reused for their primary purposes. Or they may be reused in other applications, depending upon the quality of the recycled oil. The pharmaceutical industry is an example of a case in which the recycled solvents may not be reused in the original application because of high quality requirements. However, the used solvent streams from this application can be recycled and reused in other applications, as in the ink industry, where the quality requirements are less stringent. The above discussion suggests that the contaminated liquid solvent streams offer a good potential source for energy recovery through the reclamation and reuse of these solvents. In addition to providing a potential energy recovery source, the reuse of used solvent streams will also considerably reduce the air pollution problem, since all the used solvent streams not reused or disposed of properly finally wind up in the atmosphere through evaporation.

Commercial solvent reclaimers have the capability to reclaim aliphatic, aromatic, oxygenated, and chlorinated solvents. Although few

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data are available on the total quantities presently being reclaimed, probably only a small fraction of the used solvents finds its way to the reclaimer. Some preliminary studies have been conducted to determine the economics and feasibility of in-plant reclamation of used solvents. One of the studies indicated that the savings resulting from the annual reclamation of as little as 4,000 gallons of used solvent could offset the initial capital expenditure for the required equipment. Based on the above discussion, it is recommended that the following areas be examined in detail to identify the used solvent streams and the various methods of recovery: (1) the amount of used solvents available for reclamation, (2) present and expected (in light of RCRA) disposal practices for contaminated solvents, (3) modifications desired in operating and maintenance practices to enhance solvent reclamation, (4) economics of solvent reclamation, and (5) the potential energy savings of solvent reclamation. The result would be a reference guideline manual for efficient solvent use and possible reclamation techniques.

ENERGY IMPLICATIONS OF RACT (REASONABLY AVAILABLE CONTROL TECHNOLOGY) FOR VOC EMISSION CONTROL

Most of the states are presently in the process of revising their State Implementation Plans (SIPs) to meet the air quality standards. New regulations have been proposed to control most of the primary pollutants, including the VOCs. The proposed regulations on the VOC emission control are based mainly on the application of RACT (Reasonably Available Control Technology). The implementation of RACT, in some cases, will result in energy savings due to the recovery of hydrocarbons. However, it will also result in additional energy requirements to manufacture and operate add-on pollution control equipment. Some additional energy demands may also result from the operational and maintenance requirements of RACT. Energy savings due to the implementation of RACT can be estimated based on the recovery potential of volatile organic compounds from the major emission sources discussed in this and some other EPA reports. However, to get a complete overview of the net energy impacts, it is important to estimate the additional energy demands of RACT. A detailed analysis in this regard would involve the following major tasks:

a. Identify the specific pollution control equipment requirements for various industrial categories. The RACT guidelines could form a good base for this purpose.

b. Survey and critically review the available data on the energy requirements of pollution control equipment. Other required data, not presently available, would be collected through contacts with the manufacturers of pollution control equipment and the affected industries.

c. Analyze and compile the energy requirements of implementing RACT. To assess the resulting energy demand implications accurately, individual state enforcement agencies would have to be contacted to determine the extent of RACT applicability.

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d. Recommend potential methods for reducing pollution control energy requirements while still meeting the RACT guidelines. This would partly involve reviewing the various options provided in the RACT guidelines to control hydrocarbon emissions as well as reviewing them from an energy savings or demand standpoint.

REUSE OF LIQUID HYDROCARBON STREAMS AS FUEL

Some used liquid hydrocarbon streams, other than used oils and used solvents, offer little potential for recovery as a product mainly because of their high contamination levels, difficulty of separation, and other technical considerations. These streams can, however, offer a good potential for use as fuel if properly handled and treated. The major sources of these streams are the organic manufacturing industries (basic organic chemicals, organic intermediates, plasticizers, etc.). Some of the used solvent streams can also fall under this category if they are contaminated and cannot be reclaimed for reuse as process solvents.

Data on the generation and disposal of these organic streams are almost nonexistent. Only a small fraction of the total quantities generated is presently being collected and treated for use as fuel. The remaining quantities are being landfilled or disposed of by other means. Considering the diversified operations of the chemical industry, the quantities of these miscellaneous energy-bearing hydrocarbon streams are expected to be significant. It is, therefore, recommended that a study be undertaken to evaluate the total energy potential associated with these streams. The following major tasks could be included in the study:

a. Identify the major industrial categories that generate the used liquid hydrocarbon streams (other than used oils and used solvents) and evaluate the quantities generated.

b. Analyze and evaluate the composition, organic content, heat value, and other physical and chemical properties of these streams.

c. Recommend measures to improve the quality of these streams, such as stream segregation in the plant. Study and recommend the treatment process(es) required to make them suitable for use as fuel (or in other applications) in an environmentally safe manner.

d. Study the quality control and air pollution control aspects of burning these streams as fuel.

e. The U.S. EPA should develop mechanisms that could be utilized by states, ensuring that a review of the industrial burning of this material would occur on a routine basis. Possible strategies might include developing recommended pretreatment and combustion guidelines (as mentioned above) and suggesting that

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states require industries to include information on the expected usage of such materials in their permit applications.*

IDENTIFICATION OF VOC RECOVERY POTENTIAL FROM SELECTED SOLVENT USE CATEGORIES

The total VOC emissions due to solvent evaporation have been estimated to be 7 million metric tons per year, out of which approximately 4 million metric tons per year are attributed to major applications, which include surface coating operations, degreasing, dry cleaning, use in cutback asphalt, adhesives, and graphic arts. The balance of 3 million tons of VOC are from sources for which fewer data were available to review the recovery potential. Since these source categories, when taken together, emit significant quantities of VOCs, there is value in identifying these source categories and reviewing their solvent consumption patterns, although they have not been addressed in the Control Technique Guideline documents. This identification process will provide data on applications that use significant quantities of solvent and that warrant a detailed technical study to review the applicable control technologies and to estimate the recovery potential. It may be possible to isolate some applications having considerable similarities in their VOC emission/recovery characteristics. These can, therefore, be treated as a single source category for purposes of studying the applicable control technologies.

IDENTIFICATION OF VOC RECOVERY POTENTIAL FROM INDUSTRIAL CHEMICAL MANUFACTURING APPLICATIONS

Industrial manufacturing applications account for approximately 1.5 million tons of VOCs per year. The major contribution is from chemical manufacturing applications, which mainly include a variety of organic chemical manufacturing applications. Of the various VOC emission points in chemical manufacturing applications (process, storage, fugitive, and secondary emission points such as waste water treatment), process emissions have received very little attention with respect to the proper control and recovery of VOC's. In a chemical manufacturing process, major quantities of VOC emissions are due to air oxidation, distillation columns, vacuum producing sources, and vents. Most of the existing technical studies have emphasized incineration with heat recovery as the major control technique for process VOC emissions. However, these studies were mostly directed at controlling the VOC emissions, not recovering them. Also, these analyses address only a few selected industrial processes. It is possible that some of the organics may have a reasonable chance of recovery through refrigerated scrubbing, and some other organic compounds, like benzene and toluene, can be recovered through the carbon absorption process. It is, therefore, recommended that the concentrations and compositions of selected organic exhaust streams in chemical manufacturing operations be reviewed in conjunction with individual companies or associations. And other more energy-conserving techniques should be assessed. This assessment might include working with state agencies to allow new control techniques that may require extended emission control compliance schedules.

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*Note: These guidelines for state agencies might also include used oils and solvents which are even more commonly burned by industry.

METHANE GAS RECOVERY FROM LANDFILLS

The methane gas produced in the U.S. from solid waste landfills has been estimated to be the energy equivalent of 2.45 million barrels of crude oil. Although there is presently some recovery, a large portion of the methane gas produced by the anaerobic decomposition of solid wastes is burned at the landfill sites by means of flares. Considering that the methane gas has a heating value in the range of 450-600 BTU/ft^3, its recovery provides good energy potential without extensive treatment. Except for some work now being done in California and at Argonne National Laboratory, little has been done to investigate the possibility of tapping this energy source. A study might be undertaken to examine the existing methane production from landfills, the factors involved in optimizing methane recovery, the energy recovery potential, the socioeconomic impacts, and the hazards of methane recovery.

ENERGY RECOVERY FROM RESIDUAL SOLID WASTES IN MANUFACTURING INDUSTRIES

An investigation of the recovery potential of various used liquid hydrocarbon streams in the chemical manufacturing industries indicated that some of the residual solid wastes generated in these industries may also be treated to produce a "secondary fuel." The treatment process primarily involves the pyrolysis of organic waste materials to yield condensate products that are further classified and separated for blending into fuels. These organic waste materials include tires, asphaltic products, resins, plasticizers, highly viscous paint waste, ink fountain pastes, and other organic solid wastes. Presently, two firms in Illinois are jointly pursuing this idea, and they claim to have developed and designed suitable equipment for this purpose. These firms have been working on establishing pyrolysis facilities in strategic locations within highly industrialized areas. A pyrolysis facility will act as a processing station for all the organic wastes from local industries in the vicinity. The above discussion suggests that the economic and technical feasibility of recovering energy (as fuel) from solid organic wastes by the pyrolysis process merits further investigation.

REGULATORY RECOMMENDATIONS

Compliance Dates for VOC Control Regulations for Surface Coating Industry

In surface coating applications, the use of low solvent content coatings can be an efficient and economical method of reducing hydrocarbon emissions. Presently, some industries engaged in surface coating applications (e.g., automotive and paper coating) are reverting to more expensive "add-on" control devices to meet the air pollution control regulations in the stipulated time period. Low solvent content coatings for these applications are still in the developmental stage. Therefore, it may be desirable to delay the compliance date for these industries until the research and development work on low solvent content surface coatings for these applications is completed. The present uncontrolled hydrocarbon emissions from industrial surface coating applications are estimated to be 975,000 metric tons/year. On the average, about 80 percent of these can be controlled through the use of add-on control equipment. The use of low solvent coatings, instead of add-on control equipment in some applications, will provide approximately the same degree of control, but it will also result in substantial energy savings that would otherwise have been used to manufacture and operate the pollution control equipment.

Broader Application of RACT for VOC Emission Control

Various states have proposed regulations to control VOC emissions from major source categories. These regulations are based on the application of RACT, as suggested by the U.S. EPA in its Control Technique Guideline (CTG) documents. In general, these proposed regulations will not involve a uniform application of RACT to all sources because of economic and/or air quality considerations. Therefore, the VOC recovery achieved through the implementation of proposed state regulations will be less than the figures estimated in this study. In some instances, a broader application of RACT, that is, broader than what the states will require, may be warranted for reasons of resource or energy conservation. These considerations will have to be balanced against economic feasibility. There is, therefore, a need to review the applicability of RACT as proposed in various state regulations and to assess the possibility of a broader application of RACT to improve hydrocarbon recovery.

Broader Applicability of Energy Tax Act to Used Oils and Used Solvent Streams

The National Energy Act, passed by the Congress on October 15, 1978, is composed of five different bills, including the Energy Tax Act of 1978. The Energy Tax Act of 1978 provides business tax credits for industrial investment in alternative energy property (which includes recycling equipment). However, recycling equipment, as defined in the Act, includes either the equipment used exclusively to sort and prepare solid waste for recycling or the equipment used in the recycling of solid wastes. It is recommended that the used oil and used solvent recycling equipment also be included in this definition, thus providing an incentive to increase the recycling of used liquid hydrocarbon streams.

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SECTION 5

INVENTORY AND REDUCTION/RECOVERY POTENTIAL OF GASEOUS BY-PRODUCT HYDROCARBONS

Gaseous hydrocarbons are emitted from a variety of stationary and mobile sources, with stationary sources accounting for approximately 60 percent of the total emissions. As stated in Section 2, some organics that are not hydrocarbons in the strictest definition are included as volatile organic compounds (VOC) because their effects on the ambient air quality and their recovery potential are as significant as the effects of pure hydrocarbons. An example of these non-hyrdrocarbon organic compounds is halogenated organic solvents. Since the major emphasis of this study is to identify recoverable hydrocarbon streams, the discussion and analysis in the following sections pertains only to major selected sources of VOC which can theoretically offer some recovery potential. These sources have been grouped into major source categories based upon either the process characteristics or the properties of the products resulting in hydrocarbon emissions. Table 2 gives the list of source categories included in this study. Other stationary sources of VOC emissions that have not been discussed in this study include the storage and transportation of petroleum products other than gasoline; miscellaneous manufacturing applications; forest, agriculture, and other open burning; and natural gas production.

The hydrocarbon emissions for each major source were estimated by using emission factors given in related technical literature. In order to quantify annual source emissions, these factors were then applied to published statistics on the production or the quantities of materials handled.

The VOC reduction and recovery potential was estimated whenever possible. The reduction potential represents the possible reduction in VOC emissions achievable through the application of control technology. This reduction can be due to the elimination, recovery, or destruction of VOC's. The recovery potential represents the quantities that can be recovered as a product suitable for reuse as a fuel or as an industrial product. The VOC emissions that are incinerated are not considered a part of the recovery potential, since the primary function of incineration is to destroy VOC emissions, and heat recovery is only a secondary benefit.

The VOC reduction/recovery potential for various source categories was estimated by assuming the application of relevant control technologies to the uncontrolled sources. The review of RACT (Reasonably Available Control Technology) for major sources of VOC was based mainly on the discussion in the Control Technique Guideline (CTG) documents developed by the U.S. EPA to help various states in revising their State Implementation Plans (SIP), under the requirements of the Clean Air Act. (These documents are listed as references 1 through 22.)

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TABLE 2. LIST OF GASEOUS HYDROCARBON SOURCE CATEGORIES INCLUDED IN THE STUDY

1. Petroleum Refineries
    - Crude oil storage and transportation
    - Refinery operations

2. Gasoline Marketing Operations
    - Bulk gasoline terminals
    - Bulk gasoline plants
    - Gasoline dispensing facilities (service stations and other commercial outlets)

3. Solvent Evaporation
    - Surface coating applications
    - Dry cleaning applications
    - Degreasing applications
    - Use in cutback asphalt
    - Other solvent use (graphic art, adhesives and others)

4. Industrial Manufacturing Operations
    - Paint and varnish
    - Synthetic rubber
    - Polymers
    - Other organic chemicals

5. Solid Waste Disposal

6. Miscellaneous Stationary Sources (production of crude oil, coke manufacture, pharmaceutical manufacture, stationary fuel combustion)

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These SIP revisions include proposed regulations to control VOC emissions from most of the VOC sources. However, many of the proposed state regulations do not cover small sources (and some sources located in rural areas) because of economic and air quality considerations. Therefore, the finalization and implementation of proposed rules will result in a partial application of RACT in most of the states. Although the state regulations have been proposed mainly to reduce VOC emissions going into the atmosphere, these will also result in significant recovery of VOCs.

For other source categories, the degree of correspondence between the reduction and the recovery will depend mainly on the control technology applied. Based on the above discussion, it appears that a significant part of the reduction/recovery potential estimated in this study will be achieved when various state regulations are finalized and implemented. However, the reduction/recovery potential achieved through state regulations will be less than the figure estimated in this study because most of the state regulations will not involve a uniform application of RACT to all the sources.

EVALUATION OF PREVIOUS WORK

Earlier studies of gaseous hydrocarbons have generally looked at these organic compounds as pollutants, and their project objectives included mainly the delineation of quantities, review of the control technologies, and recommendations for further control-oriented programs. Two major documents detailing the hydrocarbon emissions are the NEDS (National Emissions Data System) Nationwide Emission Summary[23] and Hydrocarbon Pollutant System Study.[24] NEDS estimates are based on the emission data provided by the state agencies and these data are compiled for all the major stationary source categories. However, a major drawback of these data is that several states have only recently completed their inventories and, in many cases, this information has not yet been incorporated into NEDS.

The Hydrocarbon Pollutant System Study was directed mainly at the development of a problem-solving research and development program for the control of hydrocarbon air pollutants from major stationary sources. The hydrocarbon emission and control technology data were developed and discussed briefly to aid in achieving this primary objective. The emission estimates in this study are for the year 1972 or earlier and therefore, needed to be updated.

U.S. EPA has published several other documents on the sources of volatile organic emissions, applicable control techniques, and environmental impacts resulting from the control of VOC emissions. Most important of these documents are the Control Technique Guideline (CTG) documents[1-22] and a document entitled Control Techniques for Volatile-Organic Emissions from Stationary Sources.[25] The CTG documents were developed for major VOC sources to inform regional, state, and local air pollution agencies of the different techniques available for reducing VOC emissions. The control techniques discussed in these documents are referred

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to as RACT (Reasonably Available Control Technology) and have been used as a base by various state agencies in proposing regulations to control VOC emissions. The latter document was developed by the U.S. EPA as a requirement under Section 108 (b) of the Clean Air Act, as amended, and was intended primarily to be used by state and local air pollution control agencies. It is a composite document detailing the control equipment and control systems for major sources of VOC. It also includes a brief and general discussion on the process and emission characteristics of various sources.

CHARACTERIZATION AND QUANTIFICATION OF HYDROCARBON EMISSIONS

The estimation of hydrocarbon emissions was based on the application of selected emission factors to the amount of material handled or produced, or to some other base variable, as applicable. The following information was included for each source category:

- Description of the source
- Emission characteristics
- Quantification of hydrocarbon emissions
- Applicable control technologies
- Recovery/capture potential

Control technologies and recovery potential could only be discussed briefly within the scope of this study. The discussion of some categories is brief because of limited data or because the categories represent sources with less significant recovery potential. In estimating VOC emissions from various source categories, the existing level of control was considered whenever possible. If no data were available on the level of existing control, the emissions were calculated based upon the assumption that the source was uncontrolled.

Petroleum Refineries

Petroleum refineries process crude oil into salable products. Major quantities of emissions occur during the storage and transportation of crude oil, during the storage of gasoline and other products, and during the refining process.

Crude oil is transported to storage facilities at or near petroleum refineries by one of the following major transportation methods: pipeline, tank truck, tank car, ship or barge. The storage facilities for crude oil, gasoline, and other products are typically large volume operations (tanks average over 150,000 bbl storage capacity) with 50 percent of the petroleum liquid stored in floating roof tanks.[26]

Operations at a refinery consist of five major steps: separation, conversion, treating, blending, and auxiliary processes. Separation processes separate crude oil into its major constituents using atmospheric distillation, vacuum distillation, and light ends recovery. Conversion processes convert less valuable components of crude oil into more valuable products using cracking, reforming, and alkylation processes. Petroleum treating processes convert unsaturated components into saturated hydrocarbons, separate fractions for further processing, and remove objectionable elements. Auxiliary processes include other indirect processes and those connected with the operation of the refinery. Equipment used in these processes include boilers, wastewater treatment units, cooling tower, etc.

Refinery Emissions. Hydrocarbon emissions from the refinery operations were estimated by the application of EPA suggested emission factors for each of the emission points.[28,29] Annual throughput values, required for the emission calculations, were obtained from the "Energy Data Reports," published by the Department of Energy.[30] Some assumptions and judgements were made to fill the existing data voids. Hydrocarbon emission estimates due to the storage of crude oil, gasoline, and other products and to the transportation of crude oil to refineries are summarized in Table 3. As the table shows, the majority of the emission losses are from fixed roof storage tanks. The ship/barge unloading losses assumed the use of submerged unloading. Hydrocarbon emissions from major petroleum refinery sources are summarized in Table 4. These estimates are based on a total U.S. refinery throughput of 5248 million barrels of crude oil per year.[30] The major hydrocarbon emission sources in refinery operations are the fluidized bed catalytic cracking unit and the blowdown systems. These together account for over 50 percent of the total refinery process emissions in the U.S.

Control Technology and Recovery/Capture Potential. A major approach to controlling evaporative losses from petroleum liquid storage tanks is to retrofit existing fixed-roof tanks with internal floating roofs and vapor recovery systems. Internal floating roofs are more commonly used because they are significantly cheaper. The control efficiency of retrofitted internal floating roofs is dependent on the condition of the storage tank and its sliding seals. However, the typical value for the control efficiency is approximately 95 percent. The loading emissions during the crude oil transportation can be controlled by the application of alternative loading methods (i.e., bottom loading) and vapor recovery equipment. Control efficiencies depend on the type of recovery equipment employed and are normally over 90 percent. The application of the above control technologies to uncontrolled emissions in Table 3 will reduce the hydrocarbon emissions by 417,000 metric tons/year.

The applicable control technologies for refinery process emissions depend on the source of emission. Hydrocarbon emissions from catalytic cracking units are usually controlled by incineration. Blowdown emissions can be effectively controlled by venting into a vapor recovery system or a flare system. The major sources of hydrocarbon emissions from the vacuum distillation column are the vacuum jets, which are used to produce vacuum. These emissions are normally vented to blowdown systems or flue gas systems. Emissions from process drains and wastewater systems are controlled by using separator covers. The fugitive emissions from miscellaneous refinery sources (cooling towers, pipeline valves and flanges, pump seals, compressor seals, etc.) can also be

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TABLE 3. VOLATILE ORGANIC EMISSIONS--PETROLEUM LIQUID STORAGE AND CRUDE OIL TRANSPORTATION TO REFINERIES

	Emission Factor[a] ($lb/10^3$ gal)	Annual Throughput[b] (10^6 gal/yr)	Annual Emissions (10^3 metric tons/yr)
Storage Tank Losses[c]			
1) Fixed Roof	-	-	384.0
2) Float Roof	-	-	64.0
TOTAL			448.0
Transportation Losses			
1) Tank Trucks & Cars[d]	2.28	4,100	4.3
2) Pipeline	0	130,100	-
3) Tankers & Barges[e]	1.33	89,800	54.1
TOTAL			58.4
Total Storage and Transportation Losses			506.4

---

[a] All emission factors from Reference 28.

[b] Annual U.S. consumption for 1977. Source: Reference 30.

[c] The emission values were estimated by extrapolating 1976 emission data in Reference 26. The ratios of crude oil refining capacities in 1976 and 1978 were used as the extrapolation factor.

[d] All tank trucks and tank cars are assumed to be unloaded without vapor recovery equipment.

[e] It is assumed that barges carry about 50 percent and tankers carry about 50 percent of the crude oil transported by water. They are assumed to be unloaded without vapor recovery equipment.

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TABLE 4. VOLATILE ORGANIC EMISSIONS--REFINERY OPERATIONS

Emission Source	Emission Factor[a] (lb/10^3bbl)	Annual Throughput[b] (10^6bbl/yr)	Annual Emissions (10^3 Metric Tons/yr)
Fluidized Bed Catalytic Cracking Units[c]			
a) Uncontrolled	220	890	88.8
b) Controlled	(Negligible)	3570	(Negligible)
Moving Bed Catalytic[c] Cracking Units			
a) Uncontrolled	87	158	6.2
b) Controlled	(Negligible)	630	(Negligible)
Fluid Coking Units			
a) Uncontrolled	(Negligible)	-	(Negligible)
Blowdown Systems			
a) Uncontrolled	580	1050	276.2
b) Vapor Recovery or Flaring	0.8	4198	1.5
Vacuum Distillation Column Condenser			
a) Uncontrolled	18	1574[d]	12.9
b) Controlled	(Negligible)	-	(Negligible)
Process Drains and Wastewater Systems			
a) Uncontrolled	200	1050	95.2
b) Controlled	10	4198	19.0
Cooling Towers (leaks into water)	10	5248	23.8
Pipeline Valves and Flanges	28	5248	66.7
Blind Changing	0.3	5248	0.7
Pump Seals	17	5248	40.5
Compressor Seals	5	5248	11.9
Vessel Relief Valves	11	5248	26.2

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TABLE 4 (continued)

Emission Source	Emission Factor[a] ($lb/10^3 bbl$)	Annual Throughput[b] ($10^6 bbl/yr$)	Annual Emissions (10^3 Metric Tons/yr)
Boilers and Process Heaters	1	5248	2.4
Miscellaneous	10	5248	23.8
TOTAL			695.8

---

[a] Emission factors from References 28 and 29.

[b] Annual U.S. consumption for 1977. (Source: Reference 30.)

[c] There was no clear data available on the number of catalytic cracking units operating with emission controls. Most of these are, however, believed to be equipped with emission control equipment because of their high emission rate and the air pollution control regulations. For estimating the emissions, 80 percent of the units were assumed to be controlled (same as in the case of blowdown systems).

[d] Assuming that, on an average, 30 percent of the total crude oil at refineries is processed in vacuum distillation columns (Source: Reference 25).

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controlled by applicable control technologies. All the above control technologies are discussed in detail in various EPA documents.[12,15,25] The application of these control technologies to uncontrolled emissions (included in Table 4) in petroleum refineries will reduce the hydrocarbon emissions by 570,000 metric tons/year.

Gasoline Marketing Facilities

Gasoline marketing facilities include bulk terminals, bulk plants, and gasoline dispensing facilities. Bulk terminals are primary distribution facilities that receive gasoline from refineries primarily by pipeline or barges and then distribute by trucks to bulk plants or to retail dispensing facilities. Bulk plants are secondary distribution facilities that receive gasoline from bulk terminals and then dispense it via account trucks to local farms, businesses, and service stations (gasoline dispensing facilities).

Major quantities of hydrocarbon emissions at gasoline marketing facilities are due to (a) storage tank breathing losses that result from the change in volume of the hydrocarbon vapor/air mixtures above gasoline and (b) working losses caused by the displacement of fluids in the storage tanks/trucks during the loading/unloading operations.

Emission Characteristics. Table 5 presents the hydrocarbon emissions at bulk gasoline terminals. These emissions were estimated based on the EPA emission factors and other data from the "Energy Data Reports."[28, 30, 31] The breathing losses were calculated for a 365 day working year and a total national storage capacity of 7,335 million gallons of gasoline at bulk terminals. Also, 75 percent of the gasoline was assumed to be stored in floating roof tanks. It was also assumed that, at bulk terminals, submerged loading was used for 90 percent of the gasoline transferred, and splash loading was employed for the remaining 10 percent of the gasoline.

Hydrocarbon emissions at the gasoline bulk plants and the dispensing facilities are summarized in Tables 6 and 7, respectively. As the tables show, major emission losses occur during the filling operations. In the case of dispensing facilities, vehicle refueling displacement losses are the other major source of hydrocarbon emissions.

Control Technology and Recovery Potential. Major control technologies to control hydrocarbon emissions at gasoline marketing facilities have been discussed in detail in U.S. EPA CTG (Control Technique Guidelines) documents.[9, 10, 11, 14] Evaporative losses from the storage tanks can be controlled by retrofitting fixed roof tanks with internal floating roofs or vapor recovery systems; internal floating roofs are more common because they are cheaper. The control efficiency of internal floating roofs is dependent on the condition of the storage tank and its sliding seals. However, the typical value for the control efficiency is approximately 95 percent. The principal controls recommended for emissions during loading/unloading operations are a vapor balance system for bulk plants and dispensing facilities and a vapor recovery system for bulk

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TABLE 5. VOLATILE ORGANIC EMISSIONS-- BULK GASOLINE TERMINALS

Loss Category	Emission Factor[a] (lb/10^3bbl)	Annual Throughput[b] (10^6gal/yr)	Annual Emissions (10^3 Metric Tons/yr)
Breathing Loss[c]			
a) Fixed Roof	.25 (per day)	27,650	75.9
b) Floating Roof	.06 (per day)	82,948	54.7
Working Losses			
a) Floating Roof			
1) Draining	.007	82,948	0.3
2) Filling	.016	82,948	0.6
b) Fixed Roof			
1) Draining	2.4	27,650	30.1
2) Filling	5.8	27,650	72.7
Tank Truck Losses			
a) Splash	12.0	11,060[d]	60.2
b) Submerged	5.0	99,538[d]	225.8
Total Breathing Loss		110,598	130.6
Total Draining Losses		110,598	30.4
Total Filling Losses		110,598	73.3
Total Truck Losses		110,598	286.0
Total VOC Emissions			520.3

---

[a] All emission factors from Reference 28. The emission factors for breathing losses are based on the tank storage capacity. Other emission factors are based on the annual gasoline throughput.

[b] Annual U.S. gasoline consumption for 1977. Source: Reference 30.

[c] Breathing losses have been estimated using the 1977 U.S. Gasoline Storage Capacity (Source: Reference 30) and 365 day operating year. The annual quantities of gasoline stored in fixed roof and floating roof tanks were estimated based on the ratio of their national storage capacities (25 percent in fixed roof tanks and 75 percent in floating roof tanks. Source: Reference 27).

[d] Assuming that, at bulk terminals, submerged loading was used for 10 percent of the gasoline transferred.

TABLE 6. VOLATILE ORGANIC EMISSIONS-- BULK GASOLINE PLANTS

	Emission Factor[a] (lb/10^3 gallon)	Annual Emissions[b] (10^3 metric tons/yr)
Storage Tank Losses		
a) Breathing losses[c]	0.4 (per day)	44.7
b) Working losses		
1) Drainage	3.9	44.0
2) Filling	4.2	47.4
Tank Truck Losses[d]		
Submerged Filling	5.0	28.2
Splash Filling	12.0	67.7
TOTAL		232.0

---

[a] Source: Reference 28. The emission factor for breathing losses is based on the tank storage capacity; other emission factors are based on the annual throughput value.

[b] Based on annual gasoline throughput of 2.4882 x 10^{10} gal/yr (Source: Reference 32).

[c] Breathing losses are calculated based on 286 day working year and a storage capacity of 50,000 gallons for each plant. Total number of bulk plants in the U.S. is estimated to be 17,400 (Source: Reference 27).

[d] Fifty percent splash filling and fifty percent submerged filling was assumed for bulk plants (Source: Reference 26).

TABLE 7. VOLATILE ORGANIC EMISSIONS--SERVICE STATIONS

Emission Point	Emission Factor[a] (lbs/1000 gallon)	Annual Emissions[b] (10^3 metric tons/yr)
Storage Tanks		
- Breathing Losses	1.0	34.7
- Filling Losses[c]		
1) Submerged Filling	7.3	127.0
2) Splash Filling	11.5	200.1
Vehicle Refueling		
- Displacement Losses	9.0	313.0
- Spillage Losses	0.7	24.3
Total Storage Tank Losses		361.8
Total Vehicle Refueling Losses		337.3
TOTAL		699.1

---

[a] Source: Reference 28.

[b] Based on an annual gasoline throughput of 76,682 million gallons/year (Source: Reference 32).

[c] Fifty percent submerged filling and fifty percent splash filling was assumed to be used for the loading of storage tanks at service stations.

terminals. The vehicle refueling losses at the dispensing facilities can be controlled by conveying the vapors displaced from the vehicle tank to the underground storage tank. The vapor balance system transfers vapors displaced from the receiving tank to the tank being unloaded; the gasoline is ultimately recovered at the bulk terminal, which is equipped with a vapor recovery system. The control efficiency of the vapor recovery system depends on the type of system (carbon adsorption, refrigeration, etc.); the typical value being over 90 percent. In the case of bulk plants and dispensing facilities, assuming that 10 percent of the emissions are lost during transportation to the bulk terminal, the net vapor recovery potential is estimated to be approximately 81 percent. Based on the above control efficiencies, the total hydrocarbon recovery potential at the gasoline marketing facilities is estimated to be approximately 1,113,000 metric tons/year. Table 8 gives a summary of the total hydrocarbon emissions and the recoverable quantities for gasoline marketing operations.

Solvent Evaporation--Industrial Surface Coating Operations

Surface coating is the process of applying paints, lacquers, varnishes, and other coatings to metal, paper, fabric, and other surfaces to form a solid protective, decorative, or adherent film after application. Compositions of surface coating (including the solvent content) vary with the end use and the type of application method. In surface coating applications, the bulk of the volatile organic (hydrocarbon) emissions occur during the main application and the evaporative or curing steps. Major industrial surface coating applications include the following: (a) metal coating (automotive, can, coil, large appliance, metal furniture, and magnet wire coating), (b) paper, film, and foil coating, (c) fabric coating, (d) coating of flat wood products, and (e) wood furniture coating.

Emission Characteristics. Major volatile organic emissions from industrial surface coating applications are due to the application of paints, varnishes, and lacquers. These emissions are summarized in Tables 9 and 10. The emission estimates were derived by using EPA emission factors in conjunction with the consumption data published by the U.S. Department of Commerce.[23,33] Information was broken down by major industrial category based on historical relative consumption data.[33] Emission data in Tables 9 and 10 also include an estimate of emissions resulting from the use of trade surface coating products. These are primarily shelf products that are sold through retail stores to the general public, professional painters, and builders. Data on VOC emissions due to the application of surface coating materials other than paints, varnishes, and lacquers were not developed; their contribution to the total emissions is relatively small and the consumption data for these materials were not readily available.

Control Technology and Recovery/Capture Potential. Volatile organic emissions from surface coating operations can be reduced either by (a) add-on control devices that destroy or collect the organic for reuse or

TABLE 8. SUMMARY OF VOC EMISSIONS AND THEIR RECOVERY POTENTIAL--GASOLINE MARKETING OPERATIONS

	Total Annual VOC Emissions (10^3 Metric Tons/yr)	Control Technique	Maximum Recovery Potential (10^3 Metric Tons/yr)
Bulk Gasoline Terminal	520.3	Retrofit storage tanks with floating roof (if not already used); recovery unit for loading/unloading operations.	423[a]
Bulk Gasoline Plant	232.0	Submerged filling and vapor balance system or loading/unloading operations.	152[a,b]
Gasoline Dispensing Facilities	699.1	Submerged filling and vapor balance system	538[b]
TOTAL	1,451.4		1,113

---

[a] Based on 95 percent control efficiency for floating roofs and 90 percent control efficiency for vapor recovery equipment.

[b] It was assumed that 10 percent of the VOC vapor is lost during transportation to the terminal. Based on 90 percent control efficiency for vapor recovery equipment, the net recovery potential for vapor collected through vapor balance system at bulk plants and dispensing facilities was estimated to be 81 percent. No specific control is considered for breathing losses.

TABLE 9. VOLATILE ORGANIC EMISSIONS--SURFACE COATING APPLICATIONS USING PAINTS AND VARNISHES

Application Type	Industry	Estimated Annual Consumption[a,b] (10^3 gals/yr)	Estimated Emissions[c] (10^3 metric tons/yr)
Industrial	Large Appliances	20,849	47.0
	Metal Furniture	12,957	29.2
	Automotive	52,888	119.1
	Sheet, Strip and Coil Coating	16,844	37.9
	Container Finishes	40,873	92.1
	Magnet Wire Insulation	11,190	25.2
	Wood Furniture	21,320	48.0
	Machinery and Equipment	16,962	38.2
	Other	139,116	313.4
Total Industrial		332,999	750.0
Trade[d,e]	-	409,446	726.6
TOTAL		742,445	1,476.6

---

[a] The total consumption data for paints and varnishes for trande and industrial applications was taken from Reference 33.

[b] The total consumption of paints and varnishes in industrial applications was broken down by industrial category based on their past relative consumption data as provided in the 1972 U.S. Census of Manufacturers published by the U.S. Department of Commerce.

[c] The emissions were estimated by using an emission factor of 1116 lbs/ton of paint and varnish consumed. This emission factor was derived by using the individual emission factors for paints and varnishes (1120 lbs/ton and 1000 lbs/ton respectively; Source: Reference 28) and their annual consumption values. The consumption figures were converted to tons/yr based on an average density of 8.9 lbs/gallon for ndustrial supplies and 12.3 lbs/gallon for trade paints and varnishes.

[d] Trade paints are shelf products that are sold through retail stores to the general public, professional painters, and builders.

[e] Only solvent-based trade paints were considered for the analysis, since other trade paints do not contribute to the hydrocarbon emissions. Solvent-based trade paints account for 48 percent of the total trade paint market. Trade varnishes were considered in totality.

TABLE 10. VOLATILE ORGANIC EMISSIONS--SURFACE COATING APPLICATIONS USING LACQUERS

Application Type	Industry	Estimated Annual Consumption[a,b] (10^3 gals/yr)	Estimated Emissions[c] (10^3 metric tons/yr)
Industrial	Automotive	16,157	44.0
	Wood	35,585	97.0
	Fabricated Metal	8,822	24.0
	Paper & Paperboard	3,469	9.4
	Miscellaneous Industrial Uses	18,337	50.8
Total Industrial		82,668	225.2
Trade[d]	-	18,737	51.5
TOTAL		101,405	276.3

---

[a] The total consumption of lacquers for trade and industrial applications was taken from Reference 33.

[b] The total consumption of lacquers in industrial applications was broken down by industrial category based on their past relative consumption data as provided in the 1972 Census of Manufacturers, published by the U.S. Department of Commerce.

[c] The total emissions were calculated by using an emission factor of 1540 lbs/ton of lacquer (Source: Reference 28). The total consumption figures were converted to tons/yr based on an average density of 7.8 lbs/gal of lacquer.

[d] Trade paints are shelf products that are sold through retail stores to the general public, professional painters, and builders.

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disposal, or by (b) process or material changes that reduce or eliminate the use of organics.

The principal add-on control devices are catalytic and non-catalytic (thermal) incinerators and activated carbon adsorbers. In general, incineration is the technique that industry uses because it is applicable to a wider range of process characteristics than are carbon adsorbers. At low concentrations of organics, carbon adsorption is a more economical approach than is incineration. For high concentrations, carbon adsorption is preferred only if the recovered organic can be reused as solvent. A detailed discussion of the above control technologies is contained in the U.S. EPA CTG documents on surface coating.[1-7]

Process and material changes provide the most diverse options for reducing volatile organic emissions from surface coating operations. The available process and material changes include new coating technologies, such as waterborne, high solids, and powder coatings; more efficient coating application methods; and ultraviolet curing of coatings. Although these changes offer great promise, they require a much longer time period for implementation than the add-on devices, mainly because most of the process and material change technologies are still in the developmental stage with a great deal of research needed before their commercial use. Table 11 gives an indication of the control efficiencies achievable by the application of control options in surface coating applications. As is evident, the control efficiency varies significantly for various coating applications even with the same control technology, primarily because of the different natures of various applications and operating practices. For the purposes of this study, the control efficiency was assumed to be 90 percent. Based on this assumption, the reduction in VOC emissions achieved by the application of control technologies in surface coating operations is 878,000 metric tons/year.

Dry Cleaning Operations

Dry cleaning is the process of cleaning fabrics in a non-aqueous solvent. The major types of solvents used are the petroleum solvents, which are mixtures of paraffins and aromatic hydrocarbons, and synthetic solvents, which are halogenated solvents (perchloroethylene and trichlorotrifluoroethane). Synthetic solvents are more commonly used in the commercial dry cleaning industry.

Emission Characteristics. The volatile organic emissions in dry cleaning operations occur because of the evaporation of solvents during the drying and cleaning operations and during the disposal of waste solvent residues, with drying and cleaning operations accounting for 76 percent of the total emissions.[24] The organic emissions are assumed to equal the annual consumption of solvents. The total estimated organic emissions from dry cleaning operations are approximately 227,000 metric tons per year. A summary of the emissions is presented in Table 12.

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TABLE 11. VOC EMISSION CONTROL TECHNOLOGIES FOR MAJOR SURFACE COATING APPLICATIONS[a]

Surface Coating Application	Control Options[b,c]	Control Efficiency[d] (%)
Can Coating	Incineration	90
	Low Solvent Coating	60 - 90
	Ultraviolet Curing	Up to 100
Coil Coating	Incineration	90 - 98
	Low Solvent Coating	70 - 95
Fabric Coating	Incineration	95
	Carbon Adsorption	90+
	Low Solvent Coating	80 - 100
Paper Coating	Incineration	95
	Carbon Adsorption	90+
	Low Solvent Coating	80 - 99
Automobile and Light Duty Truck Assembly	Low Solvent Coating	40 - 93
	Incineration	90+
	Carbon Adsorption	85+
Large Appliances/ Metal Furniture	Low Solvent Coating	69 - 99
	Incineration	90
	Carbon Adsorber	90
Magnet Wire Insulation	Incineration	90

---

[a] Source: References 2, 3, 4, and 5.

[b] The use of a particular control option, in most of the cases, is dependent on the process or the emission source in a coating application. Therefore, all the control options, indicated for a surface coating application, are not always applicable to all the emission points in that application.

[c] The efficiency of "low solvent coating" control will depend on the type of low solvent coating (water-borne, high solid, powder coating, etc.). In general, these offer only a potential alternative way of reducing emissions, since most of the low solvent coatings are in the developmental stage.

[d] In the case of "add-on" control equipment, control efficiency represents the reduction across the control device and does not take into account the capture efficiency.

TABLE 12. VOLATILE ORGANIC EMISSIONS--DRY CLEANING OPERATIONS

Solvent Type	Volatile Organic Emissions (10^3 Metric Tons/yr) Drying Operations[b]	Disposal of Solid Waste Residue[b]	Total Emissions
Halogenated			
- Perchloroethylene	120.1	37.9	158.0
- Trichlorotrifluoroethane	0.6	0.2	0.8
Petroleum[c]	51.7	16.3	68.0
TOTAL	172.4	54.4	226.8

---

[a] Source: Reference 18.

[b] It is estimated that 76 percent of volatile organic emissions are due to evaporation at the plant and 24 percent occur during the disposal of solid residue (Source: Reference 24).

[c] Petroleum solvents include Stoddard Solvents (aliphatic, boiling range 310° to 390°F) and safety solvents (aliphatic, boiling range 350° to 400°F).

Control Technology and Recovery/Capture Potential. The major control techniques to recover solvents from perchloroethylene dry cleaning operations include condensers and carbon adsorbers. The earlier units used water cooled or refrigerated condensers to control 85-90 percent of losses from the dryer. New units use carbon adsorbers to enhance the recovery of solvents. Historically, economic considerations have been the primary incentive for installing control equipment.

Collection efficiencies of carbon adsorbers range from 96 percent to 99.6 percent. Better housekeeping can also reduce vapor losses by reducing fugitive emissions (leaks from valves, flanges, seals, covers, etc.).

Two other groups of solvents used by dry cleaners are petroleum solvents and fluorocarbon solvents. Although fluorocarbons are practically inert, petroleum solvents are highly combustible and the use of emission reduction equipment in controlling petroleum solvents has not been demonstrated on an operating scale in the United States.

The loss of solvents from the waste residues, collected from the filter and distillation bottoms, can be reduced by direct and indirect distillation and by proper operation of the existing equipment. The uncontrolled and controlled emissions from various emission points in perchloroethylene dry cleaning operations are given in Table 13. There is little information available on the present extent of emission control at dry cleaning plants. One U.S. EPA document lists 35 percent of commercial units and 50 percent of industrial units using synthetic solvents presently being controlled by carbon adsorbers.[18] No specific data were available on the extent of control at dry cleaning plants using petroleum solvents. Based on an overall control efficiency of 58 percent at perchloroethylene dry cleaning plants (derived from data in Table 13), additional recovery potential achievable through the application of RACT is approximately 92,000 metric tons/year.

Degreasing Applications

Degreasing or solvent cleaning employs non-aqueous solvents to remove soils from metal and non-metal surfaces. There are basically three types of degreasers: cold cleaners, open top vapor degreasers, and conveyorized degreasers. In cold cleaning operations, the article is immersed, sprayed, or otherwise washed in a solvent at or above room temperature. Nationally, cold cleaning solvents account for almost all of the aliphatic, aromatic, and oxygenated degreasing solvents and for about one-third of the halogenated degreasing solvents purchased.

In open top vapor degreasing, the article is suspended in solvent vapors over a pool of boiling solvent. The condensation of hot solvent vapor on colder metal parts cleans the article. Most open top vapor degreasers are used during manufacturing processes in metal working plants rather than for maintenance cleaning.

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TABLE 13. VOC EMISSION DATA FOR A PERCHLOROETHYLENE DRY CLEANING PLANT

	Perchloroethylene System kg/100 kg of clothes	
	Uncontrolled	Controlled
Dryer	6	Carbon Adsorber 0.6
Discarded Filter Muck	2	1
Cartridge Filters	1	1
Discarded Still Residue	1.6	0.5 (Test Data)
Washer	2	0.1
Miscellaneous Sources	1-3	1-2
TOTAL	12	<5

Note: Uncontrolled emission estimates are best expressed as ranges because of the wide differences in operation efficiencies in the industry. These estimates are based on industry data and EPA plant tests and represent approximate mid-range for most sources. Some controlled sources are estimated.

Source: Reference 18.

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In conveyorized degreasers, a chain, belt, or other conveying system moves the article either through a spray or pool of cold solvent or through the vapor of a boiling solvent. The conveyorized cleaners can operate continuously, while the cold cleaners and the open top vapor degreasers are designed for batch cleaning.

Emission Characteristics. Most of the emissions from degreasing operations are due to bath evaporation (including diffusion and convection losses), solvent carry out, and the evaporation of waste solvent. Bath evaporation losses are increased through failure to close the cover whenever parts are not being handled. Carryout emissions result from entrainment of liquid and vaporous solvent as clean parts are removed from the degreaser. Carryout emissions are usually the major emissions from conveyorized degreasers because of the inherently large work load. Waste solvent evaporation is a source of emissions from all degreasers. It is estimated that approximately one-third of the total degreasing emissions are due to waste solvent evaporation. Estimated percentages are 45-70 percent for cold cleaners, 20-25 percent for open top vapor degreasers, and 10-20 percent for conveyorized degreasers.[20] Other degreasing emissions are due to solvent agitation and spray evaporation.

Table 14 gives the volatile organic emissions from degreasing operations by degreaser type. These emissions were estimated based on the average emission factors developed by EPA and the estimated number of degreasers currently in use.[20] Although cold cleaners have the lowest emission rate, they are the primary contributors of emissions because of large number of units in operation.

Control Technology and Recovery/Capture Potential. Major control devices used to control emissions due to solvent evaporation include improved cover, high freeborad, refrigerated chillers, carbon adsorption, and safety switches. Safety switches are devices used on vapor degreasers to prevent emissions during malfunctions and abnormal operation. Carryout emissions can be reduced by providing drainage facilities for cold cleaners and providing drying tunnels and rotating baskets for conveyorized degreasers. Emissions from the evaporation of waste solvent can be reduced by solvent reclamation. This is discussed further in the section on liquid hydrocarbon streams.

The U.S. EPA CTG document on degreasing has described control systems for each degreaser type, based on a combination of control devices and improved operating procedures.[20] These control systems are presented in Tables 15, 16, and 17. Two basic control systems are presented for each degreaser type: Control System A consists of improved operating practices and inexpensive control equipment; Control System B includes additional control equipment to increase the effectiveness of control. The control efficiencies achievable through the application of the above control systems and the resulting recovery potential are summarized in Table 18.

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TABLE 14. VOLATILE ORGANIC EMISSIONS--DEGREASING APPLICATIONS

Operation	Degreaser Type	Number of Degreasers[a] (Thousands)	Emission Factor Tons/Degreaser[a]	VOC Emissions (10^3 Metric Tons/yr) During Operations[b]	Evaporation from Waste Solvent[b]	Total
Maintenance	Cold Cleaners	910[c]	0.33	116.0	157.0	273.0
Manufacturing	Cold Cleaners	390[c]	0.66	100.0	134.0	234.0
Manufacturing	Open Top Vapor Degreaser	22	11.03	171.0	50.0	221.0
Manufacturing	Conveyorized Degreaser	4	29.77	92.0	16.0	108.0
TOTAL		1326		479.0	357.0	836.0

---

[a] Source: Reference 20.

[b] The percentage emissions due to the evaporation from waste solvent were estimated to be as follows: cold cleaners - 57.5%; open top vapor degreasers - 22.5%; conveyorized degreasers - 15.0%. Source: Reference 20.

[c] Based on 70 percent of cold cleaners used in maintenance operatons.

TABLE 15. CONTROL SYSTEMS FOR COLD CLEANING

Control System A

Control Equipment:

1. Cover
2. Facility for draining cleaned parts
3. Permanent, conspicuous label, summarizing the operating requirements

Operating Requirements:

1. Do not dispose of waste solvent or transfer it to another party, such that greater than 20 percent of the waste (by weight) can evaporate into the atmosphere.[a] Store waste solvent only in covered containers.
2. Close degreaser cover whenever not handling parts in the cleaner.
3. Drain cleaned parts for at least 15 seconds or until dripping ceases.

Control System B

Control Equipment:

1. Cover: Same as in System A, except if (a) solvent volatility is greater than 2 kPa (15 mm Hg or 0.3 psi) measured at 38°C (100°F),[b] (b) solvent is agitated, or (c) solvent is heated, then the cover must be designed so that it can be easily operated with one hand. (Covers for larger degreasers may require mechanical assistance, by spring loading, counterweighting or powered systems.)
2. Drainage facility: Same as in System A, except that if solvent volatility is greater than about 4.3 kPa (32 mm Hg or 0.6 psi) measured at 38°C (100°F), then the drainage facility must be internal, so that parts are enclosed under the cover while draining. The drainage facility may be external for applications where an internal type cannot fit into the cleaning system.
3. Label: Same as in System A.
4. If used, the solvent spray must be a solid, fluid stream (not a fine, atomized or shower type spray) and at a pressure which does not cause excessive splashing.

(continued)

TABLE 15 (continued)

5. Major control device for highly volatile solvents: If the solvent volatility is >4.3 kPa (33 mm Hg or 0.6 psi) measured at 38°C (100°F), or if solvent is heated about 50°C (120°F), then one of the following control devices must be used:

   a. Freeboard that gives a freeboard ratio[c] ≥ 0.7

   b. Water cover (solvent must be insoluble in and heavier than water)

   c. Other systems of equivalent control, such as refrigerated chiller or carbon adsorption.

Operating Requirements:

Same as in System A.

---

[a] Water and solid waste regulations must also be complied with.

[b] Generally solvents consisting primarily of mineral spirits (Stoddard) have volatilities <2 kPa.

[c] Freeboard ratio is defined as the freeboard height divided by the width of the degreaser.

Source: Reference 20.

TABLE 16. COMPLETE CONTROL SYSTEMS FOR OPEN TOP VAPOR DEGREASERS

Control System A

Control Equipment:

1. Cover that can be opened and closed easily without disturbing the vapor zone.

Operating Requirements:

1. Keep cover closed at all times except when processing work loads through the degreaser.

2. Minimize solvent carry-out by the following measures:

    a. Rack parts to allow full drainage.

    b. Move parts in and out of the degreaser at less than 3.3 m/sec (11 ft/min).

    c. Degrease the work load in the vapor zone at least 30 sec or until condensation ceases.

    d. Tip out any pools of solvent on the cleaned parts before removal.

    e. Allow parts to dry within the degreaser for at least 15 sec or until visually dry.

3. Do not degrease porous or adsorbent materials, such as cloth, leather, wood, or rope.

4. Work loads should not occupy more than half of the degreaser's open top area.

5. The vapor level should not drop more than 10 cm (4 in.) when the work load enters the vapor zone.

6. Never spray above the vapor level.

7. Repair solvent leaks immediately, or shut down the degreaser.

8. Do not dispose of waste solvent or transfer it to another party such that greater than 20 percent of the waste (by weight) will evaporate into the atmosphere. Store waste solvent only in closed containers.

(continued)

Table 16 (continued)

9. Exhaust ventilation should not exceed 20 m^3/min per m^2 (65 cfm per ft^2) of degreaser open area, unless necessary to meet OSHA requirements. Ventilation fans should not be used near the degreaser opening.

10. Water should not be visually detectable in solvent exiting the water separator.

Control System B

Control Equipment:

1. Cover (Same as in System A).

2. Safety swithces:

   a. Condenser flow switch and thermostat - (shuts off sump heat if condenser coolant is either not circulating or too warm).

   b. Spray safety switch - (shuts off spray pump if the vapor level drops excessively, about 10 cm (4 in.).

3. Major Control Device: Either:

   a. Freeboard ratio greater than or equal to 0.75, and if the degreaser opening is >1 m^3 (10 ft^2), the cover must be powered,

   b. Refrigerated chiller,

   c. Enclosed design (cover or door opens only when the dry part is actually entering or exiting the degreaser),

   d. Carbon adsorption system, with ventilation >15 m^3/min per m^2 (50 cfm/ft^2) of air/vapor area (when cover is open), and exhausting <25 ppm solvent averaged over one complete adsorption cycle, or

   e. Control system, demonstrated to have control efficiency, equivalent to or better than any of the above.

4. Permanent, conspicuous label, summarizing operating procedures #1 to #6.

Operating Requirements:

Same as in System A.

Source: Reference 20.

TABLE 17. CONTROL SYSTEMS FOR CONVEYORIZED DEGREASERS

Control System A

Control Equipment: None

Operating Requirements:

1. Exhaust ventilation should not exceed 20 m^3/min per m^2 (65 cfm per ft^2) of degreaser opening, unless necessary to meet OSHA requirements. Work place fans should not be used near the degreaser opening.
2. Minimize carry-out emissions by:
    a. Racking parts for best drainage.
    b. Maintaining vertical conveyor speed at <3.3 m/min (11 ft/min).
3. Do not dispose of waste solvent or transfer it to another party such that greater than 20 percent of the waste (by weight) can evaporate into the atmosphere. Store waste solvent only in covered containers.
4. Repair solvent leaks immediately, or shut down the degreaser.
5. Water should not be visibly detectable in the solvent exiting the water separator.

Control System B

Control Equipment:

1. Major control devices; the degreaser must be controlled by either:
    a. Refrigerated chiller,
    b. Carbon adsorption system, with ventilation ≥ 15 m^3/min per m^2 (50 cfm/ft^2) of air/vapor area (when down-time covers are open), and exhausting <25 ppm of solvent by volume averaged over a complete adsorption cycle, or
    c. System demonstrated to have control efficiency equivalent to or better than either of the above.
2. Either a drying tunnel, or another means such as rotating (tumbling) basket, sufficient to prevent cleaned parts from carrying out solvent liquid of vapor.

(continued)

TABLE 17 (continued)

3. Safety switches.

   a. Condenser flow switch and thermostat - (shuts off sump heat if coolant is either not circulating or too warm).

   b. Spray safety switch - (shuts off spray pump or conveyor if the vapor level drops excessively, e.g., >10 cm (4 in.)).

   c. Vapor level control thermostat - (shuts off sump heat when vapor level rises too high).

4. Minimized openings: Entrances and exits should silhouette work loads so that the average clearance (between parts and the edge of the degreaser opening) is either <10 cm (4 in.) or <10 percent of the width of the opining.

5. Down time covers: Covers should be provided for closing off the entrance and exit during shutdown hours.

Operating Requirements:

1. to 5. Same as for System A.

6. Down time cover must be placed over entrances and exits of conveyorized degreasers immediately after the conveyor and exhaust are shut down and removed just before they are started up.

Source: Reference 20.

TABLE 18. SUMMARY OF VOC EMISSIONS AND RECOVERY POTENTIAL--DEGREASING OPERATIONS

Degreaser Type	Uncontrolled Emissions (10^3 Metric Tons/yr)	Average Control Efficiency (%)[a]		Recovery Potential (10^3 Metric Tons/yr)	
		System A	System B	Control System A	Control System B
Cold Cleaner	507.0	50	53	253.5	268.7
Open Top Vapor Degreaser	221.0	45	60	99.5	132.6
Conveyorized Degreaser	108.0	25	60	27.0	68.4
TOTAL	836.0			380.0	469.7

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[a] Source: Reference 20.

Use of Cutback Asphalt

Cutback asphalt is prepared by cutting back or blending asphalt cement with petroleum distillates. It is used primarily in paving applications, often being sprayed directly on the road surface. Cutback asphalts are blended for different degrees of hardness or viscosity. Three basic types of cutbacks are generally used: rapid curing (RC), medium curing (MC), and slow curing (SC). All have an asphalt cement base.

Rapid curing asphalt is asphalt cement cut with a gasoline or naphtha solvent to produce a quickly evaporating blend that leaves a hard viscous base asphalt. Medium curing (MC) asphalt is an asphalt cement base cut with a kerosene distillate to evaporate more slowly than RC and leave a base asphalt of medium hardness (viscosity). A slow cure (SC) asphalt is cut with a low volatility fuel oil type of solvent to leave a soft, low viscosity asphalt that requires a long curing period.

Emission Characteristics. Hydrocarbons are emitted from cutback asphalts during storage, application and curing. Virtually all of the VOC emissions are from evaporating petroleum distillate. This distillate is an average of 35 percent (by volume) of the cutback. On the weight basis, the distillate contents are 31.1 percent for SC, 29.8 percent for MC, and 25.5 percent for RC grade. Cure type determines the percentage of diluent evaporating during the use of cutback asphalt. The average emission factors are: SC - 25 percent; MC - 70 percent; RC - 80 percent of the diluent content.[13] Table 19 compares the composition, product qualities, emission ranges, and average emission factors for various grades of cutback asphalt. Table 20 gives the estimated national emissions from the use of cutback asphalt based on the 1977 annual production estimates by the U.S. Department of Energy.

Control Technology and Recovery Potential. The VOC emissions resulting from the use of cutback asphalt are eliminated by replacing cutback asphalt with emulsified asphalt, whenever possible. Emulsified asphalt consists of asphalt suspended in water containing an emulsifier. The replacement of cutback asphalt with emulsified asphalt is practical for applications at above freezing temperatures, since otherwise the water in emulsified asphalt will freeze. Therefore, emulsified asphalts have limited application during the winter season. These asphalts have virtually no volatile organic chemicals, thus reducing the VOC emissions by almost 100 percent. The extent of reduction in VOC emissions will, however, depend on the fraction of asphalt use during the warm (above freezing temperature) season. It is estimated that emulsified asphalts are presently being used in 35 percent of the applications and 50 percent of the present cutback asphalt consumption can be conveniently replaced with the emulsified asphalts. Therefore, the additional reduction in hydrocarbon emissions resulting from the replacement of cutback asphalts by emulsified asphalts would be approximately 235,000 metric tons/year.

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TABLE 19. CUTBACK ASPHALT PROPERTIES

Type of Asphalt	Asphalt Cement Diluent	Asphalt Product	Emission Range (lbs/lb of solvent)	Avg Emissions (lbs/lb of solvent	Weight % of Distillate Product	VOC Emission Factor (lb/ton)
Cutback						
a)Rapid Cure (RC)	gasoline or naphtha	hard and	.70-.90	.80	25.5	408
b) Medium Cure (MC)	kerosene	med-hard med-viscous	.60-.80	.70	29.8	417
c) Slow Cure (SC)	slowly volatile/ non-volatile oils	soft low viscosity	.20-.30	.25	31.1	156

[a] This emission factor is calculated to provide lb of emissions/ton of cutback consumed.

TABLE 20. VOLATILE ORGANIC EMISSIONS--CUTBACK ASPHALT APPLICATIONS IN U.S.

Asphalt Type	Emission Factor (lb/ton asphalt)	U.S. Annual Consumption (10^3 Tons/yr)		Total VOC Emissions (10^3 Metric Tons/yr)
		Cutback Asphalt	Solvent	
Rapid Cure (RC)	408	725.0	185.0	134.2
Medium Cure (MC)	417	1,477.0	440.0	279.4
Slow Cure (SC)	156	794.0	247.0	56.2
TOTAL		2,996.0	872.0	469.8

Other Solvent Use

In addition to the solvent using applications discussed above, two major applications using relatively lesser quantities of solvents are printing and publishing (graphic arts), and adhesive production.

The graphic art industry consumes significant quantities of solvents in inks and diluents. The VOC emissions vary widely depending on the printing process being used, which determines the type and amount of solvent used. Gravure processes are the most significant source of emissions, since they utilize the solvent-type inks which are highly volatile. Other printing processes (lithography, letterpress, and flexography) use inks which are generally low in volatile solvent content and, therefore, emit relatively lower quantities of VOC. A breakdown of VOC emissions by printing process is given in Table 21.

VOC emissions in the graphic art industry can be reduced by the application of add-on devices (carbon adsorption, incinerator) or by the use of water-borne and low solvent inks. An evaluation of the control efficiencies of these control techniques is given in Table 22. Assuming an average overall control efficiency of 65 percent, the application of control technology will provide a reduction of 156,000 metric tons/year in VOC emissions.

The manufacture of adhesives involves dissolving plastic resins (thermoplastic and thermosetting) in organic solvents (toluene, benzene, etc.). It is estimated that the total solvent usage for various adhesive applications is approximately 481,000 metric tons/year. Major adhesive applications include flooring tile, wall covering, automobile assembly, pressure sensitive tapes and labels, glass insulation, and printing and publishing.

Besides the major solvent using applications discussed briefly in the preceding sections, there are other applications which, when taken together, emit significant quantities of VOC's. Based on a total solvent consumption of approximately 7 million metric tons per year,[24] these miscellaneous applications account for approximately 3 million metric tons of VOC emissions (assuming that the VOC emissions equal the quantities of solvent consumed). The reduction/recovery potential for VOC emissions from these miscellaneous solvent using applications could not be evaluated because no specific data were available on their solvent use.

Industrial Manufacturing Operations--Paint and Varnish Manufacture

Paint manufacturing consists of mixing, grinding, thinning (diluting with volatile organic materials like aliphatic and aromatic hydrocarbons), testing, straining, filling, and packaging operations. Major sources of VOC emissions are the grinding and thinning operations. Grinding processes produce heat which causes vaporization of volatile organic ingredients. VOC emissions during the thinning operation are due to solvent evaporation.

TABLE 21. VOLATILE ORGANIC EMISSIONS--GRAPHIC ARTS

Process	Percent of Emissions	Annual Emissions[a] (10^3 Metric Tons/yr)
Gravure	41	100.0
Lithography	28	67.0
Letterpress	18	43.0
Flexography	13	30.0
TOTAL	100	240.0

---

[a] The estimated annual emissions take into consideration the present degree of emission control (30 percent).

Source: Reference 8.

TABLE 22. VOC CONTROL TECHNOLOGY FOR PRINTING INDUSTRY

Printing Method	Printing Operation	Control Equipment	Average Overall Control Efficiency[a] (%)
Rotogravure	Publication	Carbon Adsorber	75
	Packaging	Incineration/ Water-Borne Inks[b]	65
Flexography	Publication	Incineration	60
	Packaging	Incineration/	60
		Water-Borne Inks[b]	60

---

[a] Overall control efficiency is the product of capture efficiency and control equipment efficiency.

[b] Ink composition is assumed to be 75 percent water and 25 percent organic solvent by volume.

Source: Constructed from data in Reference 8.

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Varnish manufacturing includes cooking, thinning, mixing, filtering, storing and aging, testing, and packaging. The most important step in the process is cooking, which is done in either open or enclosed gas-fired kettles. Varnish cooking emissions depend on the cooking temperature, the solvent use, the degree of tank enclosure, and the type of air pollution controls used.

Emission Characteristics. The estimated VOC emissions from paint and varnish manufacturing are given in Table 23. There is very little information available on the present extent of emission control in the manufacturing industry and therefore the above emissions were estimated based on the "no-control" assumption. Paint and varnish manufacturing cause less than 4 percent of the total VOC emissions from the combined manufacture and use of paints, varnish, and related surface coating products. These emissions are based on 1977 U.S. production totals and on 1972 census data, extrapolated to 1977. The major emissions are from trade paint manufacture, primarily due to its high producton volume.

Control Technology and Capture/Recovery Potential. The major control technologies to reduce VOC emissions from the manufacture of paint and varnish include condensers on solvent handling operations and scrubbers, carbon adsorbers, and afterburners on cooking operations. Use of the above technologies can eliminate, on an average, 95 percent of the uncontrolled emissions. Based on the total industry VOC emissions of 60,400 metric tons/year, the applicable control technologies can reduce the emissions by 57,000 metric tons/year.

Synthetic Rubber Manufacture

The two major processing technologies used in the manufacture of synthetic rubber are the emulsion polymerization and the solution polymerization. Emulsion polymerization is the more widely used process. In a typical emulsion polymerization process for synthetic polybutadiene rubber manufacture, the monomers are mixed with additives like catalysts, activators, and modifiers. The mixture is polymerized to the required conversion point, mixed with various ingredients (antioxidants, extenders), coagulated, and precipitated from the emulsion. The rubber particles are then dried and baled.

Emission Characteristics. Uncontrolled volatile organic emissions resulting from the manufacture of various synthetic rubber compounds are given in Table 24. These represent virtually all of the VOC emissions released during the production of synthetic rubbers and elastomers. Styrene Butadiene Rubber (SBR), which is the major synthetic rubber produced, accounts for over 67 percent of the total volatile organic compounds emitted during synthetic rubber/elastomer production.

Control Technology and Capture Potential. The control of VOC emissions can be achieved by thermal and catalytic oxidation, condensation, absorption with water scrubbers, and adsorption with activated carbon. Hydrocarbons recovered by solution are recycled for reuse. Based on a 75 percent capture efficiency and a 95 percent control efficiency (overall

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TABLE 23. VOLATILE ORGANIC EMISSIONS--PAINT AND VARNISH MANUFACTURE

Product Category	Emission Factor[a,b] (lb/ton)	Annual Production[c] (10^3 gal/yr)	Annual Emissions[b] (10^3 Metric Tons/yr)
Trade Paint[d]	30	402,800	16.4
Industrial Paint	30	320,000	19.6
Trade Lacquers	110	18,700	3.6
Industrial Lacquers	110	82,700	16.1
Varnishes			
a) Oleoresinous (trade)	150	5,300	1.3
b) Shellac (trade)	110	1,400	0.3
c) Electrical Insulating	150	13,000	3.1
Total Paint		722,800	36.0
Total Lacquer		101,400	19.7
Total Varnish		19,700	4.7
TOTAL		843,900	60.4

---

[a] All emission factors from Reference 28.

[b] The VOC emissions have been estimated based on no emission control.

[c] Source for production data: Reference 33. Totals are apportioned consistent with past relative consumption data as provided in the 1972 U.S. Census of Manufacturers, published by the U.S. Department of Commerce.

[d] VOC emissions result only from solvent-based trade paints which account for 48 percent of the total trade paint sales.

TABLE 24. VOLATILE ORGANIC EMISSIONS--SYNTHETIC RUBBER PRODUCTION

	Emission Factor[a] g/kg	Annual Production[b] (10^3 Metric Tons/yr)	Annual Emissions (10^3 Metric Tons/yr)
Styrene Butadiene Rubber (SBR)	5.1[c]	1,441.4	7.4
Butyl Rubber	5.1[c]	147.1	0.8
Nitrile Rubber	0.4	72.4	Negligible
Stereo Polybutadient Elastomers	19.1[d]	352.8	6.7
Stereo Polyisoprene Elastomers	19.1[d]	61.3	1.2
Ethylene Propylene Elastomers	0.4	155.4	0.1
Miscellaneous Rubbers	11.4[e]	257.6	2.9
TOTAL		2,448.0	19.1

---

[a] Source: Reference 28, unless otherwise noted.

[b] Source: Reference 36.

[c] Represents the composite emission factor for emulsion and solution polymerization (Source: Reference 37).

[d] Emission factor for solution polymerization (Source: Reference 37).

[e] Emission factor for miscellaneous rubbers was assumed to be an average of the emission factor for emulsion polymerization (3.6 g/kg) and solution polymerization (19.1 g/kg).

efficiency of 71 percent), the reduction in VOC emissions due to the application of control technology is approximately 14,000 metric tons/yr.

Plastic Manufacture

The manufacture of most plastics usually requires the polymerization of monomer and other operations like drying, treating, and forming. Polymerization takes place in a completely closed reaction vessel and the final treatment of the resin depends on the proposed use. Major emissions from the plastic manufacturing processes are from process vents (dryer, air conveyor, storage bin, etc.), reaction vessel, storage facilities, and fugitive sources of emission. A summary of the total VOC emissions resulting from the production of plastics is given in Table 25. These emissions were calculated based on the U.S. EPA emission factors and the production figures obtained from the Society of the Plastic Industry.[28, 38]

Control Technology and Capture/Recovery Potential. The emission control technology varies with the plastic type and the manufacturing process used. In the case of polyvinyl chloride, applicable control techniques include carbon adsorption, incineration, absorption, condensation, vaccum stripping, and good housekeeping. A detailed description of the specific emission points and the applicable control technologies is contained in an EPA report on the control of volatile organic emissions from stationary sources.[25] Control devices currently used in polyethylene production are flares and incineration. Emissions from polystyrene production are controlled through flaring and through refrigeration/condensation vapor recovery. The control efficiency and the reduction in emissions vary significantly depending on the type of plastic, production process, emission source, and the control technique used.

Other Organic Chemical Manufacturing Applications

The organic chemical manufacturing industries, other than paint and varnish, synthetic rubber, and plastics, emit significant quantities of hydrocarbons during the storage, processing, and equipment blowdown operations. A summary of the hydrocarbon emissions from some significant organic manufacturing operations is given in Table 26. These emission data were gathered from the reference reports and are for the year 1976. The current emissions may be somewhat different due to growth in the industry, increased usage of control, and improved processing methods. Most of these emissions are controlled through incineration and flaring, although some industrial categories employ absorption and refrigeration techniques for controlling and, possibly, for recovering the hydrocarbons. At present, there seems to be very little potential for recovering these emissions because of the economics and other process considerations.

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TABLE 25. VOLATILE ORGANIC EMISSIONS-- PLASTICS PRODUCTION

	Emission Factor[a] (lb/ton)	Annual Production[b] (10^9 lb/yr)	Annual Emissions[c] (10^3 Metric Tons/yr)
Thermoplastic Materials			
Polyethylene	(Neg.)	10.0	(Neg.)
Polypropylene	0.7	2.7	0.4
Polystyrene	(Neg.)	3.6	(Neg.)
PVC Vinyl and Vinyl Copolymer	17	5.2	20.1
Thermoset Materials			
Phenolic	(Neg.)	1.4	(Neg.)
Polyesters	(Neg.)	1.0	(Neg.)
Polyurethane	(Neg.)	2.1	(Neg.)
Thermoplastic Materials Subtotal		21.5	20.5
Thermoset Materials Subtotal		4.5	(Neg.)
TOTAL		26.0	20.5

---

[a] Source: Reference 28.

[b] Source: Reference 38.

[c] These estimates are based on no emission control.

TABLE 26. HYDROCARBON EMISSIONS FROM OTHER ORGANIC CHEMICAL MANUFACTURING OPERATIONS[a]

Organic Compound	1976 VOC Emissions (Thousand Metric Tons/yr)
Acetaldehyde	0.5
Acetic Acid	18.1
Acetic Anhydride	1.4
Acrylonitrile	83.0
Adeponitrile	5.1
Cyclohexanone	31.8
Dimethyl Terphthalate	41.3
Ethylene	63.1
Ethylene Oxide	39.0
Formaldehyde	22.2
Glycerol	7.3
Maleic Anhydride	15.4
Phenol	11.0
Phthelic Anhydride	Negligible
Vinyl Acetate	2.4
Vinyl Chloride Monomer	8.0
TOTAL	349.6

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[a] The table does not include some organic chemical manufacturing operations because of the limited data available on their hydrocarbon emissions.

Sources: References 25 and 39.

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Solid Waste Disposal in Landfills

The annual production of solid wastes in the United States from municipal and industrial sources has been estimated to exceed 492 million metric tons, of which 365 million metric tons are industrial and 127 million metric tons are municipal solid wastes.[38] Of these wastes, over 90% is interred in over 12,000 individual landfills scattered throughout the country, with 70-80% of the industrial wastes disposed of at the generation site. The remaining solid wastes are incinerated, reclaimed, or disposed of by other methods.

Landfill sites and garbage dumps are widely dispersed and are of great disparity in size. Management techniques vary from none to the very intensively managed landfills used to dispose of dangerous industrial waste. Many sites are no longer in use; others will soon be filled. Control requirements under RCRA (Resource Conservation and Recovery Act), which regulates the disposal of hazardous materials, will close down the open dumps and force more sophisticated management of the surviving landfills.

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Methane Gas Generation in Landfills

The organic constituents of solid waste disposed of in landfills decompose anaerobically, resulting in gaseous emissions that are rich in volatile organic compounds. This waste gas consists approximately of 45% CO_2, 3% N_2 and 52% hydrocarbons, with traces of pure O_2 and CO_2 included. Total estimated landfill gas generation is about 58.6 billion cubic feet annually, based on a methane generation rate of .06 ft^3/lb of waste per year.

Almost all of the landfill waste gas is presently escaping to the environment. Despite having an energy recovery potential of 450-600 BTU/ft^3 of gas, only 1% of this potential fuel source is presently being exploited. A few landfills burn off this gas by flaring, but nearly all just allow these gases to escape to the atmosphere uncontrolled.

Table 27 summarizes the total waste generation, potential VOC emissions, and potential VOC energy recovery in the United States based on the estimated 1978 waste generation for both industrial and municipal categories. The "Maximum Potential Energy/Emissions Recovery" of landfill gases is based upon the potential recovery from 90% of all solid wastes placed in landfills (or dumps) both at the site of generation (as in the case of many industries prior to the RCRA) and at a remote central dumping site (as found in landfills for municipal solid waste). The implementation of RCRA will force the increased use of these control dumping sites due to the high cost of maintaining private dumping sites in compliance with RCRA regulations.

The "Central Landfill Gas Emissions/Recovery" values listed in Table 27 represent a conservative maximum value of emission recovery.

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TABLE 27. VOLATILE ORGANIC EMISSIONS AND ENERGY RECOVERY POTENTIAL--SOLID WASTE DISPOSAL

	Waste Type		
Item	Industrial	Municipal	Total
Total waste generation (10^6 metric tons/yr)	365	127	492
Percent disposal in central landfills[a] (%)	25	90	---
Percent disposal on site[a] (%)	65	90	---
Percent disposal by incineration and other methods (%)	10	10	---
Total potential gas emissions/ recovery[b,c]			
- 10^9 ft^3/yr	43.5	15.1	58.6
- 10^{12} BTU/yr	22.6	7.9	30.5
Potential gas emissions/ recovery from central landfills[b,c]			
- 10^9 ft^3/yr	12.1	15.1	27.2
- 10^{12} BTU/yr	6.3	7.9	14.2

---

[a] Based on 1978 estimated waste generations, projected from 1976 figures and annual projected increases published in Reference 40.

[b] Based on a methane generation rate of 0.06 ft^3/lb of waste per year.

[c] Based on an average energy content of 520 BTU/ft^3 of waste gas.

The RCRA regulations and increasing energy costs could force many industries to adopt incineration with heat recovery to dispose of many solid wastes previously dumped on-site. Thus, the central landfill recovery figures represent a minimum statement of the magnitude of emissions needing control or recovery to eliminate landfill VOC emissions.

Recovery Potential

The magnitude of energy recovery potential from landfills is significant. The recoverable energy figures illustrated in Table 27 are the energy equivalent of 2.4 - 5.3 million barrels of crude oil annually. The 3.5% additional energy needed to refine this crude oil into usable products increases these figures, since negligible energy expenditure is needed to produce usable energy from landfill methane. However, problems do exist in the attempt to collect this gas. Methane digesters are only now being developed to optimize the generation process; their cost could harm the commercial acceptance of the gas. Many landfills are not presently equipped to collect methane and can not be converted economically; flaring of the gas to control emissions may be the only feasible control technique. Thus, although the potential energy recovery of landfill methane is large, the realization of this potential could take years while new landfills and digesting equipment are perfected and implemented to exploit this energy source. Currently, pilot plant projects have harnessed below 1% of the conservative maximum available energy estimate (Table 27); this figure is not expected to increase significantly in the short term.

Miscellaneous Stationary Sources

This section includes the following major miscellaneous sources of VOC emissions:

- Production of crude oil
- Coke manufacture
- Pharmaceutical manufacture
- Stationary fuel combustion

Although these sources emit significant quantities of VOC, there is insignificant potential for additional reduction or recovery of organic compounds. Therefore, the discussion on each of these source categories is brief and the VOC emission values are based mainly on the information in the reference studies.

There are three sources of volatile organic emissions in the production of crude oil: combustion sources, evaporation from storage tanks, and miscellaneous process leaks. Fugitive losses (process leaks) account for most of the hydrocarbon emissions. One study has estimated these emissions to be 89% of the total VOC emissions.[25] Data on the total crude oil production emissions are sparse. One study estimated these emissions to be about 203,000 metric tons for the total U.S. crude production of 3.33 billion barrels in 1972.[24] Based on the ratio of crude oil production in 1972 and 1977 (5.33/3.33 = 1.6), the extrapolated

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emissions for the year 1977 are estimated to be about 325,000 metric tons. Since most of these emissions are fugitive, they can be controlled mainly by regular inspection and prompt maintenance. The evaporative losses from crude oil storage tanks are presently believed to be controlled, since most of the crude oil storage tanks are fitted with floating roofs.

VOC emissions during the coke manufacturing process occur mainly during charging, coking, and discharging operations. Emissions also occur during quenching. Very little quantitative data have been reported on the VOC emissions from coke manufacturing operations. One study has reported coking emissions of 181,000 metric tons per year based on an emission factor of 4.2 lbs of VOC/ton coal.[24] However, this number should be considered a rough estimate because of the lack of good emission data. A variety of control techniques have been proposed and applied to control pollutants from coke manufacturing plants. Most techniques have been developed to control particulate emissions and the capability to control VOC emissions is secondary. Most of the coking plants have either installed the requisite controls or are believed to be in the process of installing these controls under the requirements of the Clean Air Act to meet ambient air standards.

The main processes used in the pharmaceutical industry are fermentation, synthesis, biological extraction and fractionation, and botanical extraction. The VOC emissions in all these processes are due to the solvents used. Although solvent emissions result during processing and drying, major quantities are due to the evaporation of waste solvent. The total uncontrolled emissions from all the processes have been estimated to be 41,000 metric tons for the year 1973. Most of these emissions are presently being controlled by incinerating the waste solvents. Of the waste solvents, 37 percent have been reported incinerated on site; the rest is sent to off-site contractors.[25]

VOC emissions from stationary fuel combustion sources can be due to either external combustion or internal combustion. External combustion sources include boilers for steam generation, heaters for the heating of process steams, and driers and kilns for the curing of products. Internal combustion sources include gas turbines and reciprocating internal combustion engines. VOC emissions from stationary external combustion sources are dependent on type and size of equipment, method of fixing, maintenance practices, and on the grade and composition of the fuel. The organic emissions from stationary internal combustion sources result from incomplete combustion of the fuel. The total emissions from external and internal stationary combustion sources are estimated to be 377,000 metric tons/yr. and 317,000 metric tons/yr. respectively.[25] The emissions from stationary external combustion sources can be most effectively reduced by improved operating practices and equipment designs. Proper operational practices and good maintenance are the recommended controls for minimizing emissions from stationary internal combustion sources.

A summary of the VOC emissions from the above miscellaneous source categories is given in Table 28.

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TABLE 28. VOLATILE ORGANIC EMISSIONS--MAJOR MISCELLANEOUS STATIONARY SOURCES

Source Category	VOC Emissions (10^3 Metric Tons/yr.)
Crude Oil Production	325
Coke Manufacture	181
Pharmaceuticals	41
Stationary Fuel Combustion	694
TOTAL	1,241

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Summary Discussion of VOC Emissions and Their Reduction/Recovery Potential

A summary of the VOC emissions from major stationary industrial sources is presented in Table 29, which also includes an estimate of the additional reduction/recovery potential through the application of control technology on uncontrolled sources. Reduction/recovery potential for most of the source categories is based on the application of RACT (Reasonably Available Control Technology) as suggested by U.S. EPA in their Control Technique Guideline (CTG) documents for various source categories (the reduction and recovery potential are defined earlier in this section). The above guideline documents were developed to help state agencies in revising their State Implementation Plans (SIPs) and in proposing new regulations to control VOC emissions to meet the air quality standards. Therefore, significant quantities of the VOC reduction/recovery potential estimated in this study will perhaps be achieved when state proposed regulations are finalized and implemented. The estimation of VOC emissions from various source categories considered the existing control practices whenever possible. In the case of a few source categories, no data were available on the existing controls. The emissions in such cases were calculated based on "no-control" assumption.

VOC emissions due to (1) petroleum liquid storage at refineries and (2) transportation of crude oil to refineries were estimated by updating refinery storage emission data in a recent U.S. EPA study[26] and assuming that no vapor recovery equipment was used during the unloading operations. Most of the uncontrolled emissions are due to the storage in fixed roof tanks (384,000 metric tons/year). Retrofitting these tanks with internal floating roof can reduce the emissions by approximately 365,000 metric tons/year (95 percent average control efficiency). Use of vapor recovery equipment during the unloading operations will reduce the emissions by another 52,000 metric tons/year. The total achievable VOC recovery potential from the crude oil storage and transportation operation is therefore approximately 417,000 metric tons/year. Most states have proposed regulations to control VOC emissions from crude oil storage tanks. However, these regulations cover mostly the large size storage tanks because of poor cost-effectiveness for smaller tanks. Because of this limited requirement, the expected recovery due to SIP revisions and the application of RACT will be less than the maximum achievable recovery potential presented in this study.

The major sources of VOC emissions in refinery operations are the cracking units, blowdown systems, vacuum distillation columns, and wastewater systems. Cracking units, blowdown systems, and wastewater systems are presently well controlled. Most of the states have proposed regulations to control VOC emissions from vacuum distillation columns and other refinery sources based on the CTG documents. The reduction potential for VOC emissions from refinery operations is estimated to be approximately 570,000 metric tons/year. Presently, there are no quantitative data available on the reduction potential for the refinery fugitive emissions. The control efficiency for the fugitive emissions was assumed to be 50 percent for estimating the total VOC reduction potential. The reduction

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TABLE 29. SUMMARY OF VOC EMISSIONS AND THEIR REDUCTION/RECOVERY POTENTIAL[a]

Source Category	Estimated VOC Emissions (10^3 Metric Tons/yr)	Estimated Reduction Potential (10^3 Metric Tons/yr)	Estimated Recovery Potential (10^3 Metric Tons/yr)
Petroleum Refineries			
- Crude Oil Storage and Transportation	506	417	417
- Refinery Operation	696	570	475
Gasoline Marketing			
- Bulk Gasoline Terminals	520	423	423
- Bulk Gasoline Plants	232	152	152
- Gasoline Dispensing Facilities	699	538	538
Solvent Evaporation			
- Surface Coating Applications	1,753[b]	878	NA
- Dry Cleaning	227	92	92
- Degreasing	836	380-470	380-470
- Cutback Asphalt	470	235	235
- Graphic Arts	240	156	NA
- Adhesives	481	-	NA
- Other Solvent Use	3,000	NA	NA
Industrial Manufacturing			
- Paint and Varnich	60	57	NA
- Synthetic Rubber	19	14	NA
- Polymers	21	NA	NA
- Other Organic Chemicals[c]	350	NA	NA
- Other Manufacturing[d]	222	NA	NA

(continued)

TABLE 29 (continued)

Source Category	Estimated VOC Emissions (10^3 Metric Tons/yr)	Estimated Reduction Potential (10^3 Metric Tons/yr)	Estimated Recovery Potential (10^3 Metric Tons/yr)
Solid Waste Disposal[e]	1,156	1,040	1,040
Stationary Fuel Combustion	694	NA	NA
Crude Oil Production	325	NA	NA
Total	12,507[f]	4,952-5,042[g]	3,752-3,842

NA - Not Available.

[a] These are the estimated values based on the available industry data on their operation and existing emission control practices. If no data were available on the existing controls, the estimates were derived based on the "no-control" assumption.

[b] These represent VOC emissions from only those surface coating applications that use paints, varnishes, and lacquers.

[c] These include only a few selected organic chemicals for which VOC emission data could be developed.

[d] These include VOC emissions from coke and pharmaceutical manufacturing operations.

[e] Represents the maximum quantity of methane gas that can be potentially recovered. Methane has been classified as a non-volatile organic compound by U.S. EPA because of its low volatility.

[f] These represent VOC emissions from source categories that have been considered in this study.

[g] Represents the partial total, since the values are not available for some of the source categories considered in this study.

in emissions from process fugitive leaks and wastewater systems also represents the recoverable emissions from these sources. The reduction potential from other refinery sources, except the cracking units, also represents the recovery potential, since the emissions are mostly flared or used as a fuel. In summary then, the expected recovery potential for VOC emissions from refinery operations is approximately 475,000 metric tons/ year.

Gasoline marketing operations (bulk terminals, bulk plants, and gasoline dispensing facilities) emit a significant amount of VOC's and most of these are recoverable. CTG documents on these facilities discuss the applicable controls and the recovery potential. Storage tank VOC emissions are controlled by retrofitting floating roofs on fixed roof tanks. Loading/unloading losses are reduced through the use of vapor balance at bulk plants and dispensing facilities and by vapor recovery equipment at the bulk terminals. The vapor collected at bulk plants and dispensing facilities is transported to the bulk terminals for recovery. Some losses occur during transportation, but it is still the most economical method for recovering these emissions. Although regulations have been proposed by various states in their SIP revisions to control VOC emissions from gasoline marketing facilities, these will mostly be applicable to high throughput facilities for economic reasons. Also, some facilities located in rural areas will probably be exempted from regulations because of lower ozone levels. Therefore, the actual recovery/ reduction potential attainable through the implementation of proposed rules in various states will probably be less than the recovery potential indicated in this study.

Surface coating applications are also a major source of VOC emissions. Out of a total of 1,753,000 metric tons/year emitted from surface coating applications, 778,000 tons are due to the use of trade paints and therefore cannot be controlled because of the very nature of the application. (Trade paints are shelf products that are sold through retail stores to the general public, professional painters, and builders.) VOC emissions from industrial surface coating applications (975,000 metric tons/year) can be controlled by various control technologies as discussed in CTG documents and summarized in Table 10. Based on an average control efficiency of 90 percent, the potential reduction in VOC emissions from surface coating applications is 878,000 metric tons per year if all the uncontrolled sources are adequately controlled. The recovery potential can vary from nil to a significant proportion of the reduction potential depending upon the control technique used in various applications. Among the add-on control devices available, incinerators are commonly used because of their applicability to a wide range of process characteristics and sometimes because of economics. Process and material changes (low-solvent coatings, more efficient coating application methods, etc.) provide a great potential for recovery of VOC emissions. However, many of these technologies are still in the developmental stage and, in some cases, a great deal of research is needed before their commercial implementation. (This point was discussed further in Section 4.) Because of the uncertainty about the extent of use for various control technologies in surface coating applications, it is difficult to assess the VOC recovery potential for this source category. The SIP revisions submitted by various states include proposed rules to control VOC emissions from most of the surface coating applications.

Dry cleaning operations contribute approximately 227,000 metric tons/year to VOC emissions. Major losses are from the dryer (almost 50% of the total) and most of these can be recovered through the use of condensors or carbon adsorbers. The recovery potential for VOC emissions from other emission points (filters, still residue, etc.) is relatively low because of the recovery complications. The overall average control efficiency for a perchloroethylene dry cleaning plant has been estimated to be 58 percent in the U.S. EPA CTG document on dry cleaning. Based on the above average efficiency, the additional reduction/recovery potential from perchloroethylene dry cleaning operations is approximately 92,000 metric tons/year. No estimates are presently available for additional recovery potential from dry cleaning units using petroleum solvents. Petroleum solvents are highly combustible and the use of emission reduction equipment in controlling these solvents has not been demonstrated on an operating scale in the United States.

Most of the VOC emissions from degreasing operations are due to bath evaporation, solvent carry out, and the evaporation of waste solvent. The CTG document on degreasing applications has recommended two control systems for each of the degreaser types based on the use of add-on control devices and improved operational practices. These control systems reduce mainly the bath evaporation and solvent carry out. The application of these systems on all the degreasers can reduce the VOC emissions by 380,000-470,000 metric tons/year depending upon the control system used. This figure also represents the recovery potential since the reduction is through the elimination of VOC emissions. Further recovery is possible through proper handling and reclamation of waste solvents. This is discussed further under used liquid solvent streams in Section 6.

Control technology for the reduction of VOC emissions from the use of cutback asphalt is based on the elimination of emissions through the substitution of cutback asphalt with emulsified asphalt. The total VOC emissions from this source cateogry are 470,000 metric tons/year, and approximately 235,000 metric tons/year of these emissions can be reduced/recovered through the application of above technology.

Under miscellaneous solvent use, printing and publishing and the use of adhesives are two major applications. It is difficult to control and reduce VOC emissions from the use of adhesive because of the very nature of adhesive applications. The achievable reduction in VOC emissions from the printing and publishing industry is approximately 156,000 metric tons/year based on an average overall control efficiency of 65 percent. The recovery potential depends on the control technology used (incineration, carbon adsorbers, low solvent coating) and it cannot be estimated based on available data. Besides the above, there are several other solvent using applications which, when taken together, emit significant quantities of VOC. However, the reduction/recovery potential for VOC emissions from these applications could not be evaluated because no

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specific data were available on the solvent consumption by individual application.

The total VOC emissions from major industrial manufacturing applications are estimated to be approximately 700,000 metric tons/year. It was not possible to include all the industrial manufacturing operations in the study because of their large number and the lack of sufficient information on the VOC emissions and control data for some manufacturing operations. There is very little information available on the present extent of VOC emissions control in the industrial operations and therefore the emissions were estimated based on the "no-control" assumption. Because of this assumption, the reduction potential figures for industrial manufacturing operations may be overstated.

The disposal of solid wastes in landfills generates significant quantities of waste gases which include approximately 52 percent hydrocarbons. The major recoverable constitutent is methane which, when recovered, can be used as a fuel. Presently most of the landfill waste gas is escaping to the environment. The maximum methane recovery potential has been estimated to be approximately 59 billion cubic feet or 1,040,000 metric tons/year.

In general, many and perhaps most of the sources of VOC emissions will be controlled in the next few years when the proposed regulations based on RACT for VOC emission control are finalized and implemented. At the present time, the percentage of sources which will be controlled is unknown. These regulations will probably be based on economic and air quality considerations and therefore, in general, will not involve a uniform application of RACT to all the sources. Therefore the reduction/recovery achieved through the revised SIPs will be less than the figures estimated in this study. In the case of most industrial manufacturing operations, there are few data available on the quality of the hydrocarbons being emitted and the technical and economic feasibility of recovering these emissions. There is, therefore, a need for detailed evaluation of these variables before a realistic estimate of the recovery potential can be derived.

In some instances, a broader application of RACT, that is, broader than the states will require, may be warranted for reasons of resource or energy conservation. These considerations will have to be balanced against economic reasonableness. Because of the high cost of virgin hydrocarbon materials, companies have often installed control equipment simply to recover the spent material, and payback periods have shortened considerably in some cases. Despite the fact that installing control equipment may be economically favorable, many medium-sized and smaller manufacturing companies do not realize the potential benefits and thus have not invested the capital.

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SECTION 6

INVENTORY AND RECOVERY POTENTIAL OF USED LIQUID HYDROCARBONS

INDUSTRIAL AND AUTOMOTIVE OILS

Lubricating oils can be grouped into three major categories: automotive, industrial, and aviation. The automotive and aviation categories include engine oils, hydraulic fluids, and other miscellaneous lube oils. Industrial oils include lubricating oils such as water soluble cutting oils, straight cutting oils, hydraulic oils, and gear and transmission oils. Other non-lube industrial oils include heat treating oils, transformer oils, refrigeration oils, and process oils. Railroad engine oils are also grouped into the industrial category by the Bureau of the Census. An estimate of the automotive, aviation, and industrial oil sales in 1977 is given in Table 30. The consumption data have been compiled in three major usage categories, with additional subcategories listed for each major category. These figures were derived by using data from the Bureau of Census and the National Petroleum News 1978 Factbook.[1,2]

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INVENTORY AND RECOVERY POTENTIAL OF USED OILS--QUANTITIES OF USED OIL GENERATED

The quantities of used oil generated depend on the usage category (automotive, industrial) and the major application in each category. In the automotive category, it has been estimated that approximately 57 percent of automotive lubricating oils are generated into used oil after use, the rest being consumed in use, spilled, or retained in the filter.[3] The main sources of used oil in industrial applications are the primary metal and metal working industries. In industry, oils are used in wire drawing, metal cutting, cold rolling of steel, hydraulic equipment, and production processes. Process oils used in production processes are mainly consumed in the process and become a part of the product generated. Therefore, the used oil generated from process oils is a small fraction of the total oil usage. Many "used oil factors" have been utilized to estimate the amounts of used industrial oils.

Used oil factors, developed from a State of Maryland survey for industrial and aviation lube oils, are given in Table 31.[4] The overall factor generally used is 0.50. Based on such used oil factors, the estimated quantities of used oil generated are included in Table 30. The overall quantities of used oil generated are estimated to be 1.43 billion gallons/year, with the automotive sector accounting for approximately 0.74 billion gallons and the industrial sector accounting for 0.69 billion gallons of used oil, as indicated in Table 30.

Disposal/Reuse of Used Oils

Used oil disposal practices depend on whether the oil is automotive or industrial. In the case of automotive oils, approximately 50 percent of the engine oil is sold to "do-it-yourselfers" (DIYs) who change their

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TABLE 30. OIL USAGE AND USED OIL GENERATION
(1977 ESTIMATES)

Item	New Oil Sales[a] (10^6 gal/yr)	Used Oil Generation[b] (10^6 gal/yr)
Automotive Oils		
- Engine Oils	973	
- Hydraulic Oils	222	
- Other Lubes	97	
SUBTOTAL	1,292	736
Aviation Oils	19	10
Industrial Oils		
- Hydraulic & Circulating System Oils	564	237
- Metal Working Oils	260	182
- Railroad Engine Oils	103	55
- Gas Engine Oils	108	97
- Process Oils	428	43
- Transformer Oils	78	70
- Refrigerator Oils	15	8
SUBTOTAL	1,556	692
TOTAL	2,867	1,438

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[a] Source: References 1 and 2.

[b] Based on used oil generation factors given in Reference 4.

TABLE 31. INDUSTRIAL AND AVIATION USED OIL FACTORS

Industrial and Aviation Lube Oils	Used Oil Factor[a]
Hydraulic & Circulating System Oils	0.42
Metal Working Oils	0.70
Railroad Engine Oils	0.53
Gas Engine Oils	0.90
Aviation & Other	0.50
Other Industrial Oils	
Process Oils	0.10
Electrical Oils	0.90
Refrigeration Oils	0.50

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[a] Ratio of used oil to oil sold.

Source: References 4 and 8.

TABLE 32. USED OIL DISPOSAL METHODS EMPLOYED BY "DO-IT-YOURSELFERS"

Disposal Method	Relative Frequency (%)
Dump in backyard or elsewhere on property	33.6
Take to service station	15.6
Take to public dump	11.6
Dump in storm sewer	11.4
Dump in garbage can	10.7
Dump in empty lot	3.4
Pour down toilet	0.9
Sell	0.6
Pour down sink	0.4
Use around the house	0.6
Other means of disposal	11.2
TOTAL	100.0

Source: Reference 6.

own motor oil or add oil to makeup for the volume lost in the engine.[5] Most of these DIYs use environmentally unsatisfactory disposal methods, which presently provide little chance for collection and reuse. Table 32 presents the results of an EPA study on the used oil disposal methods employed by DIYs.[6] Used automotive lubricating oils generated at service stations, garages, and truck and auto fleets are mostly collected by used oil collectors. Most of this collected oil is either reprocessed for use as industrial fuel, re-refined into lube stock, or used for dust control. Based on a survey done for the State of Oregon, it was estimated that approximately 71 percent of the used automotive oil collected by used oil collectors in Oregon was reprocessed for industrial fuel and 22 percent was used for dust control.[7] The remaining 7 percent was re-refined into lube stock.

Used industrial oil disposal is accomplished in a variety of ways. A plant has basically three alternative ways to remove the accumulation of used oil:

1. The oil can be hauled away by an independent collector.
2. The plant itself may haul the oil away.
3. The oil may be disposed of or reused on the plant premises.

The major methods of disposal or reuse of industrial oils can be classified as follows:

1. Recycling--processing used industrial oils for reuse as lube or hydraulic oil
2. Road oiling and dust control--spreading oil on roads, principally to reduce fugitive dust emissions
3. Fuel supplement--blending used oil with virgin oil for combustion
4. Treatment Plant--treating oil-water mixture in wastewater treatment facility
5. Dumping--spreading on land or in waterways for disposal
6. Deposition in landfill--mixing oil with solid wastes for burial in landfill
7. Incineration--burning oil for the purpose of volume reduction
8. Sewage disposal--dumping used oil-water mixtures into sewer systems

Based on the available information, most used industrial oils are presently being disposed of by these methods. A rough percentage of used oil disposed of by various methods can be obtained from a survey done for

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the State of Illinois and presented in an Illinois Institute of Natural Resources document.[8] Some results of the survey are given in Figure 2. As the figure shows, on average, only 30 percent of the total oil purchased annually can be readily accounted for by the plants surveyed. In primary metal and metal working plants, a portion of the oil leaves the plant in a product form, such as in new machines requiring an oil coating. A small percentage of oil is consumed in plant processes, such as vaporization during quenching. A larger percentage of the oil leaves a plant as solid waste in filter cartridges or in oil absorbent materials, which are sprinkled on the floor around machinery. However, the total of all these potential oil flow paths generally would not come close to the missing 70%.

These results indicate that a very large percentage of the oil used every year in the plant cannot be accounted for at the present time by plant personnel. In rare cases, an oil audit is performed for a single process, but this is usually not true for the entire plant.

Recovery Potential of Used Oils

Theoretically, almost all of the used oil generated (1.43 billion gallons/year, as shown in Table 30) should be recoverable. However, the actual percentage that is technically and economically feasible to recover depends on many variables--oil type and quantity used, level of contamination, storage facilities. At the present time, used automotive oil generated by the "do-it-yourselfers" presents the most difficult recovery problem because it is widely dispersed. And most individuals do not take the collected used oils to the nearest service station or to a collection center. Various programs are presently being initiated in many states to set up used oil collection centers at strategic locations and to encourage DIYs to bring their used oil to them.

In the case of used industrial oils, the present recovery is far below the theoretical quantity presented in Table 30 (692 million gallons/year). For several reasons, most plants have not established comprehensive used oil accounting and reuse programs. Since the cost of lubricants has traditionally been a very small portion of production costs, industry has had little incentive to track the use of oils. This attitude has been gradually changing for both environmental and economic reasons. First, the Resource Conservation and Recovery Act (RCRA) will require "cradle to grave" accounting of hazardous waste, and used oil has been declared hazardous in the proposed regulations. Second, although the cost of lubricants is still relatively small to the manufacturing plant, the cost of lubes and other oils has skyrocketed. A few larger companies have begun recycling programs for energy and dollar conservation.

The immediate reasons for oil loss and stream quality degradation are (1) poor handling and maintenance procedures, (2) nonexistent or poor oil use and disposal accounting, (3) inadequate used oil storage and stream segregation, and (4) insufficient knowledge of techniques for extending oil life and recycling spent oils.

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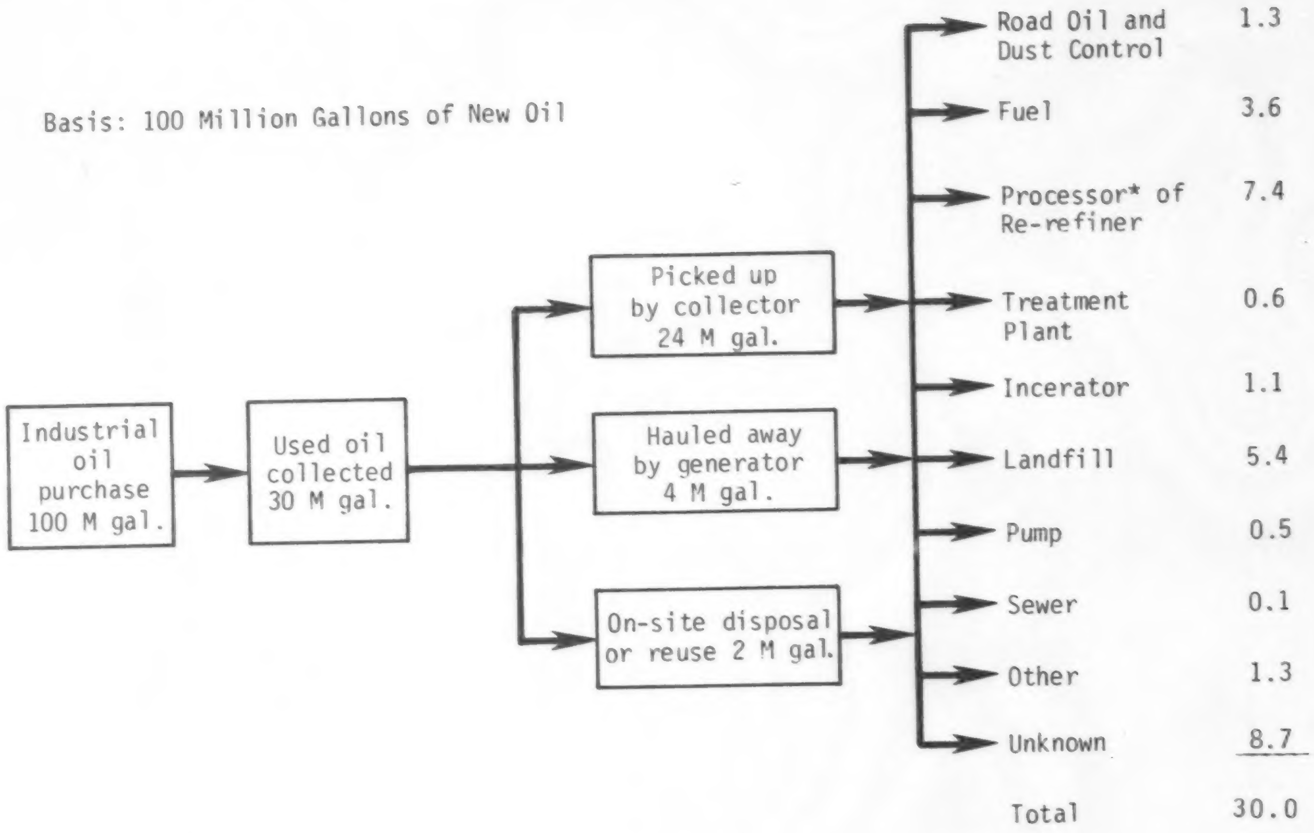
Basis: 100 Million Gallons of New Oil
Industrial oil purchase 100 M gal.
Used oil collected 30 M gal.
Picked up by collector 24 M gal.
Hauled away by generator 4 M gal.
On-site disposal or reuse 2 M gal.
Road Oil and Dust Control 1.3
Fuel 3.6
Processor* of Re-refiner 7.4
Treatment Plant 0.6
Incerator 1.1
Landfill 5.4
Pump 0.5
Sewer 0.1
Other 1.3
Unknown 8.7
Total 30.0

*The principal product of the processor is fuel oil.

Figure 2. Typical disposal and reuse pattern for used oil.

Source: Reference 8.

An extensive audit of oil usage and disposal practices is the first step toward developing a conservation program, such as an audit pointing to machine losses and poor handling problems. Oil stream segregation is extremely important because mixing various oil streams after use reduces the overall quality of the used oil stream. Some oils are comparatively dirty, may be contaminated with solid materials, or may have a high water content. One typical example is the mixing of used lube oil streams with the used coolant stream (which is predominantly water with soluble oils). Efforts should therefore be made to provide separate drainage and after-use storage for oils with vastly different compositions. The segregated materials can often be readily reclaimed and recycled back into the oil stream, rather than requiring disposal. It can be a costly and cumbersome process to provide additional plumbing and tank storage facilities for separate storage. However, it might be worthwhile if the quantity of used oil collected is substantial and if a large portion can be reclaimed for reuse.

Economic Factors in Reusing Used Oils

Presently, the major markets for used oil utilization are the industrial fuel market and the road oiling market. For road oiling applications, once the used oil has been collected, almost no pre-treatment is employed before application to the road surface. The used oil can be directly applied even when it contains the lead and other heavy metals present in used crankcase oils or any of the contaminants present in used industrial oils. The substitute for used oil in road oiling applications is usually a virgin product. Therefore, the use of waste oil for road oiling represents a substantially higher profit than if virgin oil were used. However, employing used oil for road oiling provides a major source of water pollution. An EPA study on road oiling concluded that only 1 percent of the total oil applied to the test roads remained in the top inch of the road surface.[9] The balance quantities left the road by simple runoff and by flotation during wet weather. Some contaminants in used oils, lead, for example, if associated with dust particles on the road, can be carried by winds to contaminate fields and crops adjacent to the oiled road. In the EPA's proposed hazardous waste guidelines, used oil is classified as a hazardous substance. The passage of this regulation will eliminate the use of used oil for road oiling.

The most common reuse of used oil is as industrial fuel. Usual pre-treatment before reuse involves removal of water and solid particles through gravity settling and/or filtration. Used oils are normally mixed with virgin fuel oils for proper burning, although some small plants burn 100 percent used oil. Since there is a significant price differential between the used oils and the virgin oils, used oils look very attractive as a fuel alternative.

Re-refining can also be an attractive market for used oils from an economic point of view, but this depends greatly on the level of contamination and the distance to the re-refiner. Some claim it to be the most beneficial method of recycling from a resource conservation point of view.

Recycling and Re-refining of Used Oils

Since the vast majority of oil is not consumed or chemically changed while performing its primary function, it could be reused after undergoing varying degrees of cleansing. The oil can be re-refined into good lubricating oil or used as a feedstock in the manufacture of other petroleum products. In many cases, the oil can often be reclaimed to nearly original quality, significantly prolonging useful oil life. Often this can be done within the industrial plant itself. The oil can also be reprocessed for use as fuel oil, as previously mentioned, and in many instances can be burned safely without any further flue gas treatment.

Recycling processes remove unwanted contaminants to produce useful products. Used oils will generally contain sludge, water, and varying concentrations of heavy metals and other substances that may have entered the oil through use or that may originally have been oil additives. An example of the last case is the organic sulfides frequently added to oil to inhibit oxidation.

Recycling consists of either reclaiming used oil or the more thorough processes of reprocessing and re-refining. Some well-segregated industrial oils may be recycled through reclaiming, which removes only solids, water, and perhaps small percentages of other materials--products of oxidation, for example.

Reclaiming is a process that employs one or more of the following physical processes:

- Use of Heat (150°F-200°F)
- Gravity Settling
- Centrifugation
- Vibrating Screening of Solids
- Use of Surfactants (e.g., demulsifiers)
- Dehydration
- Filtration

Reprocessing involves the same pretreatment elements as reclaiming, but in addition, acids, alkalis, amines, and/or solvents may be used to remove materials such as water and solids. Reprocessing of oils may produce clean fuels, form oils, certain lubricants, and possibly process oils.

Re-refining is the most thorough recycling process. It may employ distillation and steam stripping of pretreated oils, usually with activated bleaching clay, in addition to the physical and mechanical processes involved in reclaiming and the chemical additives involved in reprocessing. This process removes light ends and remnants of contaminants not removed in pretreatment. In general, re-refining means the application of processes that not only use gravity, heat, and physical separation techniques such as filtering, centrifuging, and dehydrating (reclaiming) but that also proceed further through the application of distillation, fractionation, and/or chemical processes to recover the oils for reuse. Re-refining produces fuel (distillate) and lubricating oil base stocks which can be used for motor oils, transmission fluids, gear oils, cutting oils, hydraulic oils, and quench oils.

Re-refining Processes. Major re-refining processes currently in use include the following:

- Acid/Clay Process
- Clay Treatment
- Caustic - Clay Treatment
- Propane Solvent Extraction Process

Other re-refining processes currently under development are the Distillation-Hydrotreating Process, BETC Solvent Process, and MZF Solvent process. Table 33 gives the salient features of re-refining processes.

The acid/clay process has traditionally been the workhorse of the re-refining industry. However, its acid sludge and oily residue are environmentally undesirable; it also has a relatively lower yield than some of the newer processes. The clay treatment process was used mainly in the days before automotive lube oils were highly contaminated with additives. It uses higher concentrations of clay than those employed in the acid/clay process and is capable of producing an acceptable quality oil. Its main advantage over the acid/clay process is the elimination of acid sludge, just as its advantage over the caustic-clay treatment is the elimination of caustic sludge. The propane solvent extraction process includes a short preliminary distillation, extraction with propane, treatment with acid, vaccum distillation, and finishing with clay. This process does not totally replace acid/clay treatment but does reduce the usage of these materials and the amount of waste generated.

Among the re-refining processes currently under development, the BETC solvent process is being developed by Bartlesville Energy Technology Center in Bartlesville, Oklahoma. In this process, a mixture of organic solvents is used (instead of the acid) for the extraction, and either clay or hydrogenation can be used for finishing the oil. This process has been tested to give a better yield than the acid/clay process and does not generate any acid sludge. A distillation-hydrotreating process is being developed by a division of the Exxon Research and Engineering Company and consists essentially of vacuum distillation followed by a hydrogenation process for finishing the oil. Exxon has concluded, however, that it would be difficult to try to license the process to many small re-refiners and has placed the technology in the public domain. MZF solvent extraction process is based on two solvent extraction techniques that require aqueous isopropyl alcohol solutions in conjunction with small amounts of alkali or acid to remove contaminants from the used oils. In addition to the above processes, Phillips Petroleum Company has developed a new re-refining process, Phillips Re-refined Oil Process (PROP), and has signed a contract with the State of North Carolina to build a 2 million gallon per year plant.

TABLE 33. SALIENT FEATURES OF VARIOUS RE-REFINING PROCESSES

Process	Implementation	Product Quality	Process Yield	Process Energy Requirements	Process Complexity	Other
			Existing Processes			
Acid-Clay	Widely used	Can produce a quality lube oil	Low (65 percent) when processing used automotive lube oils	Low (12,000 Btu per gallon of product)	Simple, and adapted to small volumes and batch operations. Can be adapted to semi-continuous operations	Produces acidic sludge and oily clay waste products
Clay	Limited use, one known plant producing automotive lube oil	Questionable for highly contaminated oils, acceptable for industrial oils	Low (60 percent) for automotive lubes and high (90 percent) for industrial oils	Same as acid-clay (12,000 Btu per gallon of product)	Very simple	Produces oily clay waste product
Caustic-Clay	Limited use, one known plant producing automotive lube oil	Although thought questionable for highly contaminated oils, production of a quality lube oil is claimed	Low lube oil yield (62 percent) offset by concurrent production of fuel oil (16 percent)	About 40 percent higher than acid-clay (17,000 Btu per gallon product) if all energy is charged to lube production	Comparable to acid-clay process	Produces caustic sludge and oily clay waste product
Propane Extraction	Newly developed process with two European plants in production	Can produce a quality product	Yield unresolved high yield (82 percent) claimed by process developer. Moderate yield (70 percent) reported by plant operator	Very high, more than 2 x acid-clay (28 to 32,000 Btu gallon of product)	Relatively complex and suited to large scale operations Propane section operates on a continuous basis. The acid-clay finishing step can be either batch or semi-continuous	Requires an acid-clay finishing step

(continued)

TABLE 33 (continued)

Process	Implementation	Product Quality	Process Yield	Process Energy Requirements	Process Complexity	Other
			Proposed Under Development			
Distillation-Hydrotreating	Several variations of process exist. Two distillation (no hydrotreating) plants in production. Demonstration plant under construction in W. Germany, and small pilot plant in operation in the U.S.	Should be capable of producing a quality lube oil	Significantly higher than for acid-clay (76 percent)	Slightly higher than for acid-clay (13,000 Btu per gallon of product)	Somewhat complex and suited to large scale continuous operations	Requires solution of distillation column fouling and catalyst poisoning problems
BETC Solvent	Pilot plant operation has produced re-refined oil for engine sequence and field tests	Producing high quality oil that nearly passed all engine sequence tests for an SE oil rating (and probably would have with slightly larger quantities of certain additives)	Higher than acid-clay (71 percent)	Highest of any process evaluated due to need to recover large volumes of solvent (33,000 Btu per gallon of product)	Relatively complex. Currently engineered for semi-continuous operation. Could be used for batch operations	Product lube oil currently undergoing vehicle field testing
MZF Solvent	Laboratory (test tube) stage. Process evaluation based on these data. Has least development work of processes reported	Laboratory data report good removal of metallic contaminants, which should produce quality lube oil after undergoing subsequent fractionation and clay contacting	Significantly higher than acid-clay process (76 percent)	About 2 x acid-clay (25,000 Btu per gallon of product)	Should be comparable to other solvent extraction processes, and suited for semi-continuous or batch operations	Emulsion separation by centrifugation replaced by use of an undisclosed de-emulsification agent, whose cost is claimed to be low

Source: Reference 3.

Energy Considerations of Re-refining. The energy saving potential of used oil re-refining is dependent on the process used for re-refining as well as the energy consumed in producing virgin lube oil. It is also dependent on the base of comparison: the saving potential of recovery will be relatively less if the used oils are used for combustion purposes rather than being dumped as a waste material. Three different comparisons have been made. Table 34 gives the energy and resource savings per gallon of used oil recycled. The table also shows the total savings realized by repeated recycling of used oil during its "lifetime," a term used to describe the number of times it can be re-refined until only five percent or less of the original quantity of oil is yielded. Since this lifetime saving is the true measurement of the conservation potential of re-refining, the total equivalent energy and resource savings over the recycling lifetime of a gallon of oil have been calculated for both the existing and the "under development" re-refining processes.

Table 35 shows the potential savings in energy and in crude oil resources available through the recycling of all the used oils generated in the U.S. (1,438 million gallons/year). As the table indicates, approximately 20 million barrels of lube stock could be saved annually by using the existing processes; advanced methods would yield 29 million barrels annually. This assumes that all of the used oil has completed a single re-refining cycle in a year; additional savings would be accrued if part of the oil was repeatedly recycled during the year. These figures should be considered strictly as an upper theoretical boundary of potential oil savings.

Table 36 gives a comparison of the energy savings realized by re-refining and burning of the used oils. As the table shows, recycling may be a superior method for energy/resource conservation based on the data developed in a government study.[3] However, these studies have not taken into account all of the transportation, segregation, and other pretreatment energy costs. Not all the used oil is presently available for recycling because of collection difficulties and other technical factors. These problems have been instrumental in the widespread burning of used oil in industry.

SOLVENTS--NEW SOLVENT INVENTORY

The consumption of virgin solvents in 1978 for selected solvents in major categories of commercial application is shown in Table 37. These solvents are all halogenated hydrocarbons, ketones, and alcohols. The solvents listed were included in this table because they are not used exclusively as "chemical building blocks" but are also employed in applications in which they retain their basic chemical identities after use.

Table 37 shows that halogenated hydrocarbons are most commonly used as aerosol propellants, refrigerants, and solvents, with total demand presently between 300-350 thousand metric tons per year for all but trichloroethylene.

TABLE 34. ENERGY AND RESOURCE SAVINGS PER GALLON OF OIL RECYCLED

Re-refining Process	Average Process Yield (%)	Maximum Number of Recycles Possible[a] (lifetime)	Total Oil Savings per Re-refined Gallon (gal.)	Total Process Energy Saved by Re-refining[b] (10^3 BTU)	Total Equiv. Energy of Crude Oil Saved by Re-refining[c] (10^3 BTU)	Total Equiv. Crude Oil Saved by Re-refining (gal.)
Existing						
Clay Caustic/Clay Acid/Clay	62	7	1.6	-10.4[d]	210.6	1.52
New Processes or Those Under Development						
Propane Solvent MZF BETC Dust/Clay	76	11	3.0	36	450.3	3.26

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[a] The maximum number of recycles possible is the number of times used oil can be re-refined until 5% or less of the original quantity of oil is yielded. This is the lifetime of the oil for our study.

[b] Process energy savings are from Reference 3.

[c] The energy content of the re-refined used oil has been calculated based on an average value of 138,000 BTU/gallon.

[d] Negative sign indicates that the process energy required for re-refining is less than the process energy requirement for manufacturing new oil.

TABLE 35. ANNUAL ENERGY/RESOURCE SAVINGS BY RECYCLING RECOVERABLE USED OIL

Item	Re-refining Processes	Re-refining Processes Under Development
Average Process Yield (%)	62	76
Recoverable Used Oil (10^6 gal/yr)	1,438	1,438
Annual Re-refining Cycles	1	1
Energy Savings by Re-refining		
(i) Process Energy		
- Per gallon of used oil[a] (10^3 BTU/gal)	(6.5)[b]	12.0
- Total (10^{12} BTU/yr)	(9.35)[b]	(17.26)[b]
- Equivalent crude oil Saving[c] (10^6 BBL/yr)	(1.61)[b]	2.98
(ii) Resource Energy		
- Quantity of recylced oil (10^6 gal/yr)	891.6	1092.9
- Equivalent crude oil saving (10^6 BBL/yr)	21.23	26.02
Net Equivalent Crude Oil Saving (10^6 BBL/yr)	19.62	29.0

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[a] Source: Reference 3.

[b] Numbers in parantheses denote net saving.

[c] Based on a heat content of 138,000 BTU/gallon of oil.

TABLE 36. POTENTIAL ENERGY/RESOURCE SAVINGS FROM USED OIL RE-REFINING RELATIVE TO COMBUSTION

Re-refining Processes	1978 Attainable Used Oil Recovery	Lifetime Total Equivalent Energy Saved by Re-refining		Energy Released by Combustion of Used Oil		Re-refined Energy Conserved - Combustion Energy Conserved	Oil Saved by Re-refining Used Oil Instead of Burning	
	(10^6 gal/yr)	(10^3 BTU/gal)	(10^{12} BTU)	(10^3 BTU/gal)	(10^{12} BTU)	(10^{12} BTU)	(10^6 gal)	(10^6 BBL)
Existing	1,438	211	303	138	198	105	761	18
New Processes or Those Under Development	1,438	450	647	138	198	449	3254	77

TABLE 37. INVENTORY OF INDUSTRIAL SOLVENTS

		Commercial Applications		
Solvent	Demand[a] (10^3 Metric Tons)	Uses	% of Total[a]	Consumption (10^3 Metric Tons/yr)
Halogenated Hydrocarbons				
- Fluorocarbons	309	Aerosol Propellants	24	74
		Refrigerants	39	121
		Solvents	11	34
		Blowing Agents	12	37
		Other	14	43
- Perchloroethylene	323	Dry Cleaning Solvent	60	194
		Industrial Metal Cleaning	15	48
		Chemical Intermediate	13	42
		Other	12	39
- Trichloroethylene	125	Vapor Metal Degreasing	87	109
		Other	13	16
- 1,1,1 Trichloroethane	334	Cold Cleaning	50	167
		Vapor Degreasing	25	84
		Adhesives	7	23
		Aerosols	7	23
		Other	11	37
- Methylene Chloride	302	Paint Remover	30	91
		Aerosols	20	60
		Solvent Degreasing	10	30
		Plastics	5	15
		Other	35	106

(continued)

TABLE 37 (continued)

Solvent	Demand[a] (10^3 Metric Tons	Commercial Applications Uses	 % of Total[a]	 Consumption (10^3 Metric Tons/yr)
Ketones				
- Acetone	956	Chemicals & Plastics	60	573
		Pharmaceutical	5.5	53
		Coatings Solvent	10	96
		Other	24.5	234
- Cyclohexane	151	Adipic acid for Nylon 6-6	58	87
		Caprolactan for Nylon 6	23	35
		Other	19	29
- Methyl Ethyl Ketone	256	Coatings Applications	67	172
		- Vinyl Coatings	34	
		- Nitrocellulose Coatings	14	
		- Acrylic Coatings	12	
		- Misc. Coatings	7	
		Adhesives	14	36
		Lube Oil Dewaxing	7	18
		Other	12	30
- Methyl Isobutyl Ketone	89	Protective Coating Solvent	70	63
		Rare Metal Extraction	5	4
		Other	25	22

(continued)

TABLE 37 (continued)

Solvent	Demand[a] (10^3 Metric Tons)	Commercial Applications		
		Uses	% of Total[a]	Consumption (10^3 Metric Tons/yr)
Alcohols				
- Ethanol	95	Chemicals	48	46
		Cosmetics & Toiletries	16	15
		Coatings	13	12
		Detergents, Flavors, Disinfectants	11	10
		Food and Drug Processing	6	6
		External Pharmaceuticals	3	3
		Other	3	3
- Isopropanol	876	Acetone	38	333
		Other Chemicals	7	61
		Coatings & Other Solvent Uses	30	263
		Drugs and Cosmetics	10	88
		Other	15	131
- Methanol	557	Formaldehyde	43	240
		General Process Solvent	10	56
		Chemicals	24	134
		Other	23	127
TOTAL	4,373			

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[a] Source: Reference 10. All consumption figures are projections for 1978 based on 1975, 1976, 1977 and partial 1978 data.

Ketones, shown in the table, have a wider range of demand from less than 100 thousand to over 950 thousand metric tons per year. Primarily used in chemicals, plastics, and coating applications, they are also employed in the adhesives and pharmaceuticals industries. The most common ketone, acetone, accounts for two-thirds of the national annual ketone consumption.

Alcohols are the most widely employed solvent types. Besides their use in the detergent, food and drug processing, and cosmetic industries, they have applications in most of the industrial categories dominated by halogenated hydrocarbons and ketones. Table 37 shows that two of the most-consumed solvents inventoried are alcohols--isopropanol (876 thousand metric tons per year) and methanol (557 thousand metric tons per year).

Reclamation/Reuse Potential

Of all the commercial applications mentioned in Table 37 and in the preceding paragraphs, only certain usage categories generate waste liquid solvent streams that are potentially recoverable. These categories primarily include those industries employing solvents for cleaning metals, clothing, or other materials. However, applications such as vapor degreasing utilize solvent vapors for the actual cleaning process and then condense these vapors to minimize solvent losses and improve operating economy.

The general process of solvent reclamation is diagrammed in Figure 3. This basic type of process train may exist in-plant if the consumer uses sufficient solvent quantities to economically justify the apparatus, operating and maintenance costs. Generally, plant use must exceed 500 kg/day to justify in-plant recovery; otherwise, the services of a solvent reclamation contractor are often cheaper than the total cost of a reclamation process train.

The typical reclamation process consists of six unit operations. The first unit operation includes solvent storage and handling. Both drum and tank storage are common methods of storing used solvent for future processing. Similarly, after processing, the solvent is also stored for future use, thus making this description applicable to both the first and fifth process unit operations.

The second unit operation includes initial solvent treatment, using vapor recovery or mechanical separation of the solvent from contaminants. The factors considered in selecting the initial treatment method for liquid waste solvents are primarily the solvent miscibility and the solids content of the waste solvent. For waste solvent vapors, many factors determine the method of initial treatment. These factors include the solvent vapor composition, air concentration in the gas stream, solvent boiling point, solvent reactivity, gas stream composition, solvent vapor concentration, and solvent solubility. These factors determine the use of either adsorption, absorption, or vapor condensation techniques. If the components of the solvent mixture recovered by these

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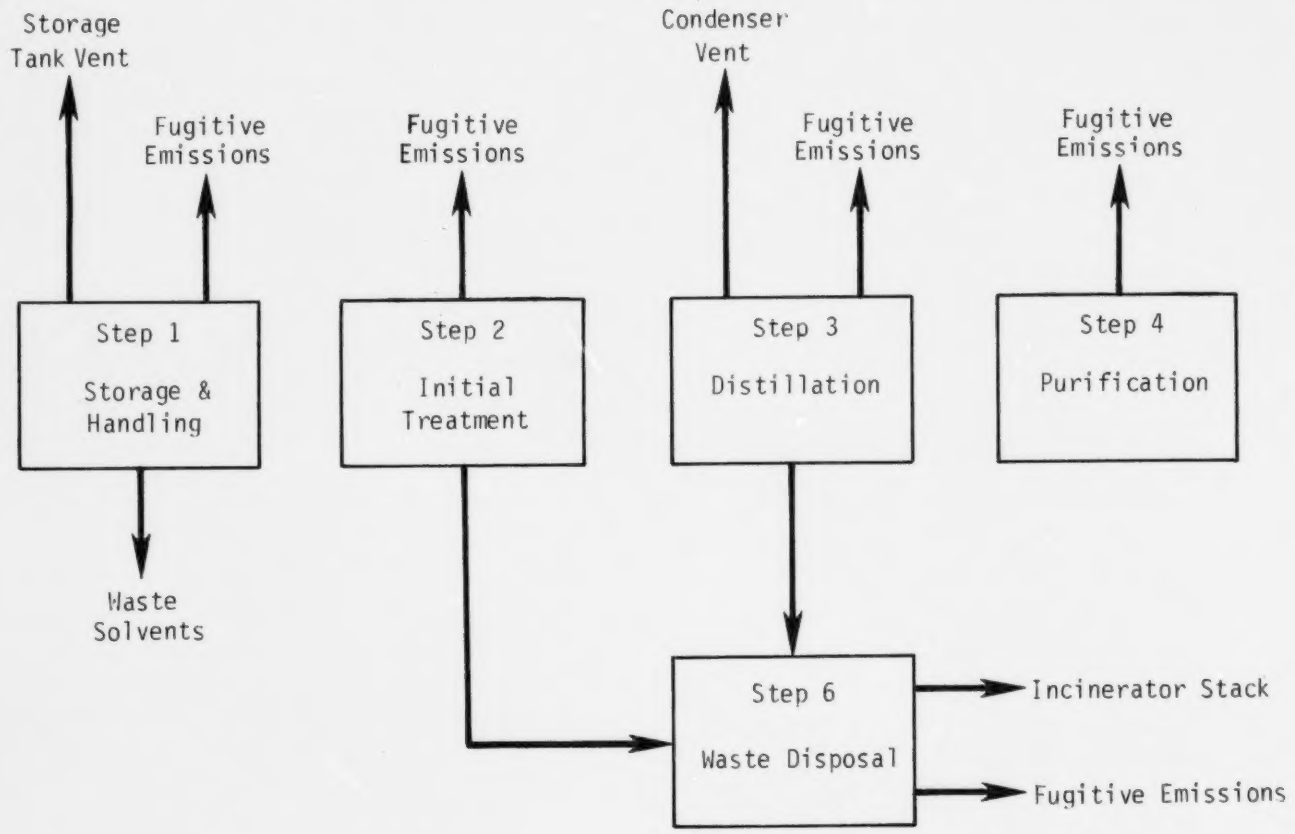
Storage Tank Vent
Fugitive Emissions
Step 1 Storage & Handling
Waste Solvents
Fugitive Emissions
Step 2 Initial Treatment
Condenser Vent
Fugitive Emissions
Step 3 Distillation
Fugitive Emissions
Step 4 Purification
Storage Tank Vent
Fugitive Emissions
Step 5 Storage & Handling
Reclaimed Solvent
Step 6 Waste Disposal
Incinerator Stack
Fugitive Emissions

Figure 3. General reclamation scheme for solvent reuse.

techniques can be reused without further separation and are immiscible in water, they can be sent directly to purification without going through a distillation column (which would separate the different solvents in a used solvent mixture).

The initial treatment of liquid waste solvents is accomplished through mechanical separation, an operation feasible if the solvent is immiscible in water. Mechanical separation methodology includes decantation, filtration, drainage, sedimentation, and centrifuging. All methods except decantation are used to remove undissolved solids from solvent; decantation separates water from immiscible solvent. Often, a combination of these methods is used.

Distillation, the next (third) unit operation available in the reclamation process, is used to separate solvent mixtures and to remove dissolved impurities by one of five distillation methods. Three of the methods (simple batch distillation, simple continuous distillation, and steam distillation) are suitable for the separation of solvents from dissolved contaminants. To separate mixed solvents, multiple distillation or rectification (use of a fractionating column) is required.

The purification of solvent (operation 4) is accomplished by elimination of water from immiscible solvent, followed by stabilization of the dewatered liquid. Dewatering is accomplished by either decantation or the salting of the solvent/water mixture, that is, passing it through a bed of $CaCl$ to absorb any water. This dewatered solvent then is stabilized, if necessary, by the addition of buffers to keep solvent pH constant during use. This reclaimed solvent is then stored until needed.

The final consideration, and an important one in determining additional reclamation potential in the process train, is waste disposal. The waste materials separated from solvents during initial treatment and distillation are disposed of by incineration, landfill, or deep well injection. Approximately 80% of the waste generated by private solvent reclamation contractors is disposed of by incineration, with most of the remainder dumped in landfills; deep well injection is seldom used. The composition of this waste is highly variable and can contain up to 50% solvent. This solvent content facilitates pumping and handling. Waste constituents include the following: oils, pigments, waxes, greases, detergents, organics, metal fines, resins, dissolved metals, and vegetable fibers. The corrosivity in still bottoms and other wastes increases as solvent content of the waste stream is decreased.

Not all of these unit operations exist in every solvent reclamation process; in-plant reclamation is often more simple (or more complex) than the general description provided. Solvent usage and economics determine plant size and complexity.

Solvent reclamation in commercial and industrial applications is presently minimal, largely due to the relatively low cost of many virgin organic solvents. However, more stringent environmental regulations, coupled with the increased cost and uncertain long-term availability of

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petroleum-based solvents, may make solvent recovery more attractive in many areas.

The primary applications in which comparatively widespread solvent recovery and reclamation are practiced use synthetic, or halogenated, hydrocarbons. The high initial cost of these solvents makes their reclamation economically attractive, and thus, they have become a mainstay of the private solvent reclamation contracting industry.

Drycleaning is an industry totally based on solvent usage. All drycleaning processes use solvents, and many use the halogenated hydrocarbon solvent, perchloroethylene. Due to its high cost, this synthetic solvent is almost always recovered after use. The recovered solvent is then filtered prior to reintroduction into the process stream, or it is reclaimed in another manner (distillation). Many plants still use Stoddard or 140° safety solvent for drycleaning, and almost all reclaim the liquid waste solvents. Overall, approximately 85% of the plants using petroleum solvents reclaim them, and 93% of the total combined solvent usage in the drycleaning industry is reclaimed. Additional liquid recovery potential for this industry primarily exists in the increased reclamation of the solvent in still bottoms, but the handling problems resulting could exceed the slight benefits accrued. Table 38 shows the estimated volume of each type of recovered solvent and the overall industry recovery data.

The cleaning and degreasing of metals using solvent is a common practice in many industries that work with metal. The process of metal cleaning/degreasing is simple: The metal part contacts a bath of either liquid or vaporized cleaning solvent. The chemical action of the solvent dissolves or carries away unwanted grease, metal chips, and other material. Primarily, the cleaning/degreasing solvents used are halogenated hydrocarbons or various petroleum-based mineral spirits. Liquid waste streams are generated from the drainage of highly-contaminated solvent tank bottoms, which also may have a high solids content due to sediment buildup. These liquid wastes are generated for all three types of degreasing/metal cleaning operations (cold cleaning, open top vapor degreasing, conveyorized degreasing), but the recovery rates vary greatly among them. Table 38 shows individual degreasing/ metal cleaning process liquid waste solvent generation rates and gives overall recovery statistics. The recovery rates for degreasing and metal cleaning could be increased by eliminating carry-out solvent losses. A drainage trough can be used to catch the carry-out solvent runoff. However, the major area of loss is waste solvent evaporation after disposal. Only 45% of the generated liquid waste solvent is recycled.[12] This is because over 80% of the waste liquid stream is generated by cold cleaners, which are primarily small units using annual solvent quantities too small to justify in-house reclamation equipment, especially if inexpensive petroleum solvent is used. Reclamation of this solvent is presently encouraged by centralized reclamation companies through economic incentives such as payment for used solvent and price discounts on the purchase of new solvents. Based upon the RCRA Proposed Guidelines for Hazardous Waste Disposal of December 1978, these solvent waste streams are hazardous and must be properly disposed of by the generator. This disposal cost will prompt increased reclamation.

The surface coatings industries are generators of waste liquid solvent from cleanup operations, spills, and spoiled batches. All are ancillary sources, and they generate minute liquid solvent streams when compared to the gaseous solvent emissions generated by this industrial category. Present recovery rate is rather low due to the nature of the solvent usage. The recovery rate should improve after passage of the revised RCRA hazardous waste provisions, which will include these solvents as hazardous wastes. Table 38 shows present recovery statistics for liquid solvent streams in this industrial category.

Although other industries generate waste liquid solvent streams, few statistics on a national basis could be developed. This was primarily because industries such as canning, chemical manufacture, rubber and plastics manufacture, consider solvent usage data as proprietary information which, if indiscriminately disclosed, could reveal process information to competitive firms. A study of consenting companies in major solvent-consuming industries might be one solution to this dilemma. Such a study would establish solvent usage, waste solvent recovery potential, and the amount of in-plant solvent recovery practiced by these industries.

OTHER USED LIQUID HYDROCARBON STREAMS

In addition to the used oils and used solvent streams, other major but less significant streams of used liquid hydrocarbons are generated from the manufacturing of basic organic chemicals, coal tar and derivatives, organic intermediates, plasticizers, and electrochemical resins. Although on a national basis no quantitative data can be easily developed for the liquid hydrocarbon streams generated from these industries, they are expected to be very significant. These streams may often offer little potential for recovery as a product, primarily because of high contamination levels, difficulty of separation, and other technical considerations. However, these can offer a good potential for energy recovery through their use as a fuel. The overall heat value of these combustible streams depends very much on their composition and the extent of inorganic matter that does not contribute to the energy value.

The treatment of combustible used hydrocarbon streams involves the filtration, dewatering, and blending of various in-bound streams to achieve a set of usable parameters. The following list of parameters is sought for optimum combustion in existing equipment:

Flash Point	150-200°F
Ash	less than 5%
BTU Content	13,000 to 16,000 per lb
Sulfur	less than 1%

TABLE 39. SOLVENT RECOVERY FROM WASTE LIQUID STREAMS IN SOME MAJOR INDUSTRIES

Industry Operation	Process	1977 Waste Liquid Solvent Generated (10^3 Metric Ton/yr)	Present Recovery Rate[a]	Liquid Waste Solvent Available for Reclamation (10^3 Metric Ton/yr)
Dry Cleaning	Total	52.4	0.93	48.9
	Trichlorotrifluoroethane	0.18	0	
	Petroleum Solvent Processes	17.4	0.85	14.8
	Perchloroethylene Processes	34.8	0.98	34.1
Degreasing & Metal Cleaning	Total	357	0.45	161
	Cold Cleaning	291	0.45	131
	OT Vapor Degreasing	50	0.45	23
	Conveyorized Degreasing	16	0.45	7
Surface Coatings[a]	Total	15.3	0.34	5.2
	Trade Paint Mfr.	4.6	0.34	1.6
	Industrial Coatings	6.1	0.34	2.1
	Putty and Misc. Products	1.6	0.34	.5
	Industrial and Trade Lacquer Mfr.	3.0	0.34	1.0

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[a] Source: References 11, 12, and 13.

Chlorides	less than 1%
Heavy Metals (Cd, Cu, Cr, Zn, Pb, Ni)	less than 250 ppm
Water Content	less than 1%

One major consideration in improving the quality and fuel value of these streams is the separation of various streams in the plant. Quite often, the industries tend to mix liquid hydrocarbon streams with predominantly water-bearing wastes, thereby making all of the mixture difficult to separate. Specific examples of this practice are the adhesive and paint industries which produce both latex and water-based materials, as well as solvent-modified resin cuts.

Fuel derived from the used liquid hydrocarbon streams is different from the petroleum oil (either #2 or #6 fuel oil) in its properties. It differs from petroleum oils in flow characteristics, air-to-fuel ratio, pump requirements, and pressure requirements. It has much lower viscosity than other fuel oils and, therefore, requires much lower pressures for both movement and atomization. Also, its lower BTU rating requires that more be used to achieve the temperatures or steam pressure normally required by the plant processes.

Utilizing used liquid hydrocarbon streams as fuel also requires different environmental considerations than does the utilization of conventional fuel oils. The heavy metals present in these streams sometimes oxidize upon incineration and many are particularly hazardous when airborne. This problem can often be overcome by using scrubbing or baghouse filtration before exhausting the stack gases to the atmosphere. The second environmental concern deals with the presence in the fuel of chlorinated organic constituents that would convert to hydrochloric acid upon incineration. Hydrochloric acid causes corrosion and subsequent air pollution. When present, therefore, chlorinated organic constituents should be removed from the used liquid hydrocarbon streams before burning these streams as fuel. These types of hydrocarbon streams are now being burned at an increasing rate in many areas of the country.

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SECTION 7

REGULATIONS CONTROLLING USED HYDROCARBON STREAMS

Various federal and state regulations have been promulgated to control the emissions and/or disposal of used hydrocarbon streams. The regulations governing the emissions of gaseous hydrocarbons are required by the provisions of the Federal Clean Air Act; that is, since many areas have not achieved the ambient standard for ozone, states must take measures to reduce the ozone level. One step in reducing ozone concentrations is to reduce precursor emissions of volatile organic compounds. The used liquid hydrocarbon streams are regulated by federal and state laws on the disposal of waste streams and resource recovery.

This section reviews the gaseous hydrocarbon emission control regulations being written under the Clean Air Act Amendments of 1977 and outlines the principal laws affecting the ultimate destination of used liquid hydrocarbon streams.

USED GASEOUS HYDROCARBON STREAMS

The Federal Clean Air Act is the major regulation directed at controlling all the air pollutants, including ozone. Since hydrocarbon (or volatile organic compound) emissions result in an increase in ozone concentrations, they are also required to be controlled by state and federal regulations under the Clean Air Act. The 1970 Clean Air Act Amendments required the U.S. EPA to promulgate National Ambient Air Quality Standards (NAAQS) for the major pollutants in order to protect the public health and to meet other environmental and economic values. The 1970 amendments also required each state to adopt an implementation plan to control emissions at least to the extent necessary to attain the NAAQS and to maintain them thereafter.

The 1977 amendments of the Clean Air Act required each state to make recommendations to the U.S. EPA concerning the areas within the state deemed in attainment, nonattainment, or unclassified with respect to the NAAQS. Also, the states were required to implement additional regulations to help achieve state and federal clean air goals. To help the states revise their state implementation plans and achieve the NAAQS, the U.S. EPA developed guidelines for the control of volatile organic compound (VOC) emissions from stationary sources. These guidelines reflect EPA's judgment as to what constitutes reasonably available control technology (RACT). The RACT guidelines have been developed for almost all of the major sources of VOC. These RACT documents provide a brief description of the industry, major hydrocarbon emission points, emission control technology, cost analysis, and the environmental impacts of applying the technology. The RACT documents are also helpful in estimating the hydrocarbon capture/recovery potential from various industries. Section 172 of the Clean Air Act requires a State Implementation Plan for attainment of a primary NAAQS to provide for attainment as expeditiously as possible, but no later than December 31, 1982. However, if it can be demonstrated that attainment of a primary NAAQS for carbon

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monoxide or ozone cannot be achieved by that date, then Section 172 (d)(2) provides that the attainment must be achieved no later than December 31, 1987.

The RACT guideline documents have presently been written for 22 categories. Most states have submitted or are planning to submit revised State Implementation Plans (SIPs) incorporating the major elements of these documents.

LAWS AFFECTING USED LIQUID HYDROCARBON STREAMS

The federal government has proposed various regulations to control solid and liquid waste disposal practices and to conserve resources, in general. The most prominent among these are the Resource Conservation and Recovery Act, the Energy Policy and Conservation Act and the Federal Water Pollution Control Act. These regulations have a direct bearing on used oil recovery programs.

Resource Conservation and Recovery Act (RCRA)

RCRA, an amendment to the Solid Waste Disposal Act, seeks both to strengthen controls over solid and liquid waste disposal practices and to encourage increased recovery and reuse of waste products. RCRA provided three major programs to help reach the above goals: (1) the establishment of a hazardous waste-control program, (2) the establishment of a land-disposal regulatory program in each state, and (3) the initiation and support of resource-conservation programs by state and local governments to conserve resources and reduce the amount of solid waste requiring land disposal.

RCRA covers both hazardous and non-hazardous wastes. The Federal Register of December 18, 1978, proposed that used oil be declared a hazardous material. Therefore, used oils will probably have to meet all the provisions of the section on hazardous wastes. Hazardous wastes are covered under Subtitle "C" of RCRA which includes the following major elements:

1. Identification and listing of hazardous wastes (Section 3001).
2. Standards applicable to hazardous-waste generators (Section 3002). This section requires generators of hazardous waste to provide for proper record keeping, proper labeling of containers, and a manifest system to direct and track the movement of waste from the point of generation to ultimate disposal.
3. Standards applicable to hazardous-waste transporters (Section 3003), requiring them to comply with the manifest system and maintain proper records.
4. Standards applicable to the operators of disposal facilities (Section 3004), requiring them to comply with the manifest

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system, to use satisfactory disposal techniques and practices, and to provide for the maintenance and operation of the facilities.

5. Permits for storage, treatment, and disposal facilities (Section 3005).

6. Other requirements for inspections, federal enforcement, and notification.

Subtitle "D" of RCRA covers all wastes not classified as hazardous. This requires that all land-disposal sites meet the sanitary landfill criteria, and if a site handles hazardous waste, it will have to meet the additional more stringent requirements of Subtitle "C".

Section 3002, which requires generators to follow the path of the hazardous waste to its final disposal, will probably have the greatest impact on industrial in-plant used oil and solvent recycling. Used oils and many solvents would be considered "hazardous" materials because they generally contain contaminant levels greater than the threshold values proposed in the December 18, 1978, Federal Register.

These regulations would force industry to take a hard look at the types and volumes of these wastes, and many companies, seeking to reduce the volumes of hazardous wastes that require special handling and disposal, will begin reclaiming used oils and solvents.

Energy Policy And Conservation Act (EPCA)

Section 383 of EPCA requires that the Federal Trade Commission prescribe a labeling standard for containers of recycled oil, indicating any particular end use for which a determination has been made of the substantial equivalency between the used oil and a virgin oil product. The Federal Trade Commission labeling regulations are to preempt all other labeling rules which address comparative characteristics of recycled oil. The EPA is also required to issue labeling standards applicable to containers of new oil, used oil, and recycled oil, relating to the proper disposal of such oils after use. The purpose of EPA labeling requirements is "to reduce to the maximum extent practicable, environmental hazards and wasteful practices associated with the disposal of such oils after their use." At this time it appears there may be a joint labeling effort between the FTC and the EPA.

The emphasis on labeling requirements by the Federal Trade Commission arose due to the perceived importance of previous changes in FTC labeling requirements in depressing the used oil recycling industry. The National Bureau of Standards is presently conducting studies to determine if standard physical and chemical bench tests can be developed to establish the equivalency of recycled used oil and virgin oil in terms of their lubricating properties.

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The EPA requirements for the labeling of containers of new, used, or recycled oil are directed at the alternative disposal problems associated with oil, rather than at the FTC Consumer Protection Program regarding the labeling of performance characteristics. The EPA requirements will, therefore, have an impact not only on the economics of recycling lubricating oils but also on the economic viability of all potential reuse and disposal programs for industrial oils.

Federal Water Pollution Control Act

The Clean Water Act and the Federal Water Pollution Control Act (PL 92-500) and subsequent legislation and regulations created the concept of an incompatible pollutant (40 CFR 128 and 40 CFR 129), and the National Pollutant Discharge Elimination System (NPDES). The following statement of policy was reiterated and strengthened by the Clean Water Act (PL 95-217).

> The Congress hereby declares that it is the policy of the United States that there should be no discharges of oil or hazardous substances into or upon the navigable waters of the United States, adjoining shorelines, or into or upon the waters of the contiguous zone [PL 92-500 (FWPCA) Sec. 311 (b)(1)].

The concept of compatible wastes is applicable to the workscope of this report only when oil wastes infiltrate publicly owned treatment works and, further, when such oil wastes fit the definition of wastes not compatible with publicly owned treatment works. Such wastes can be prohibited, and the source industries must pretreat them whenever the publicly owned treatment works receiving the wastes so requests. As an example, the Metropolitan Sanitary District of Greater Chicago and the State of Illinois require a 30 day average of 24 hour composite readings of not more than 15 mg/l for fats, oils and/or greases. A 24 hour maximum of 30 mg/l and a single grab sample maximum of 75 mg/l is also required. These limits are also specified in the Illinois NPDES general requirements for discharges to Illinois waters. However, other sanitary districts have maximum requirements as great as 100 mg/l. These districts must be able to treat the sewage stream so that the receiving water (assuming the body of water is a navigable water of the U.S.) meets the appropriate state standards.

The U.S. EPA has implemented The Clean Water Act (and FWPCA) by establishing water quality standards along with the NPDES system and by developing control technology guidelines. It should be noted that these federal efforts establish water quality standards that the states are expected to attain by establishing their own discharge regulations and NPDES permit requirements. The standards for oil wastes will be included in the guidelines that are yet to be developed. However, present federal policy (personal communication Bob Pearson U.S. EPA Region V) is not to allow oil discharges that will produce a visible "sheen" on the receiving

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body of water. The toxicity requirements for water quality are 1/10 of the 96 hour LC_{50} level for any pollutant classified as toxic under the authority of PL 92-500 (sections 301 et seq.) When quantitative standards are set by the various states, these requirements are often set between 5 mg/l and 15 mg/l (personal communication D. DeClu, IEPA, 11/79).

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State Used Oil Regulations

In view of the growing awareness of the reuse potential of used oil, many states have initiated state-level used oil recycling programs. State laws have also been passed to encourage the recycling of used oils and to avoid unsatisfactory disposal of waste streams.

The State of Illinois has passed a Special Waste Hauling Regulation designed to prevent illegal disposal of "special" wastes by haulers. Special wastes are considered in three categories: hazardous wastes, pollution control residues, and industrial process effluents. The proposed regulation has two principal parts: (i) a permit requirement for special waste haulers and (ii) a manifest system for the generators, haulers, and receivers of special wastes. Much of this regulation is similar to proposed RCRA regulation.

The Illinois recycling plan has been in effect for over a year. At this point its effect on the recycling of wastes is unclear. The State has also initiated a program to increase the public awareness of the recycling potential of automotive crankcase oil and the problems of indiscriminate disposal. Used oil collection centers have been set up at strategic locations where "do-it-yourself" oil changers can deposit their used oil. To increase the efficiency of oil collection at industrial plants, Illinois Institute of National Resources sponsored a study to prepare an oil audit and reuse manual. The State of Oregon has conducted a similar used oil recycling program based on the provisions of its House Bill #3077.

The Utah Oil Re-Refinement Act (1977) is aimed at increasing the amount of oil going to re-refiners. Re-refiners must report on the methods of disposal of re-refined waste products in order to obtain a permit. Both automotive and industrial sources of used oil are required to dispose of oil only to used oil dealers or to re-refiners. Used oil dealers have the option of selling used oil to re-refiners or disposing of it elsewhere. Other disposal techniques are not regulated in the law. The Utah law was based in part on legislative findings that used oil disposal practices constituted an environmental and health hazard.

Seven states have now passed some types of legislation related to used oil disposal. These laws are generally directed toward crankcase oils. The thrust of the laws range from a mere statement of support for recycling programs to required comprehensive manifest systems and the licensing of re-refiners.

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